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« On-the-go » multispectral imaging system to characterize the development of vineyard foliage

Bourgeon M.A.[1], Paoli J.N.[1], Villette S.[1,]Debuisson S.[2], Morlet M.[2], Jones G.[1], Gée C.[1]
[1]*AgroSup Dijon, UMR 1347 Agroécologie -26, bd Docteur Petitjean BP 87999 – 21079 Dijon Cedex – France*
[2]*Comité Interprofessionnel du Vin de Champagne, 5 rue Henri Martin, 51200 Epernay - France*
jn.paoli@agrosupdijon.fr

Abstract

In Precision Viticulture, multispectral imaging systems are currently used in remote sensing for vineyard vigor characterization but few are employed in proximal sensing. This work presents the potential of a proximal multispectral imaging system mounted on a track-laying tractor equipped with a Greenseeker RT-100 to provide an NDVI index. The camera acquired visible and near-infrared images which were calibrated in reflectance. Vegetation indices were computed and compared to Greenseeker data. From two of the resulting datasets, a spatio-temporal study of foliage description through both optical systems is presented. This first study assessed the proximal imagery regarding the similarity of results.

Keywords: precision viticulture, multispectral imaging, in-field acquisition, NDVI, foliage characterization.

Introduction

Precision viticulture makes use of multispectral imaging systems in remote sensing to characterize vine vigor and within-field spatial variability (Johnson, 2003). In proximal sensing, multispectral techniques are developing and several studies show its potential to characterize vine leaves in the field including disease detection applications (Tirelli et al, 2012) and leaf area characterization (Tregoat et al, 2001; Diago et al, 2012). The first study led by Tregoat et al (2001) presented inconclusive results, explained mainly by the many technical limitations of the devices used: black and white images and an appropriate background. The second study used RGB images with a better image processing method: this study resulted in a better correlation between leaf area measured (with a leaf area meter) and leaf area estimated by means of the images. However, other technical limits are listed, mainly associated with light control to improve image quality. This may explain the timid development of multispectral imaging systems as mounted proximal sensor for vine foliage characterization.

In proximal sensing, other tools, such as the Greenseeker RT-100 sensor are used to characterize vines. It is a commercially available ground-based sensor which characterizes grapevine vegetation. This active sensor generates red and near infrared light. It uses light reflectance to compute NDVI (Normalized Difference Vegetation Index, Rouse et al, 1973). The Greenseeker RT-100 was assessed by the "CIVC (Comité Interprofessionnel du Vin de Champagne)" technical institute for vine foliage characterization of high density vineyards (Debuisson et al,2009). It is a robust sensor providing a reliable index in outdoor conditions. It must be noted however that the

measurement precision depends on the distance between the target and the measuring head of the Greenseeker (Kim et al, 2012). In the case of vine foliage, Drissi et al (2009) noted that the NDVI delivered by the Greenseeker is related to vine vigor by two parameters: VLAI (Vertical Leaf Area Index) and gap fraction (porosity).
The aims of this study were: 1) to compare the performance of this multispectral imaging system and the Greenseeker through vine foliage characterization and 2) to evaluate the vine vigor by means of these two systems.

Materials

Experimental field

The experiments were conducted in the field of a CIVC experimental site situated near Epernay (Chouilly, Marne), France. The area of the field measures 0.72 ha and it was planted in 1996 with a high density of vines. Indeed, the inter-row distance is 110 cm, the distance between vine stocks is 120 cm, and the trimming height is 127 cm (around 90cm of vine foliage height). The field is composed of 45 rows of grapevines. The plot was been divided into three areas according to the slope (high, medium, and low), and three grapevine varieties were planted on each area: Pinot Noir (PN), Chardonnay (CH), and Meunier (Mn). Nine blocks were thus delineated and the planting followed a Latin-Square pattern. The field organization is described in Figure 1a.

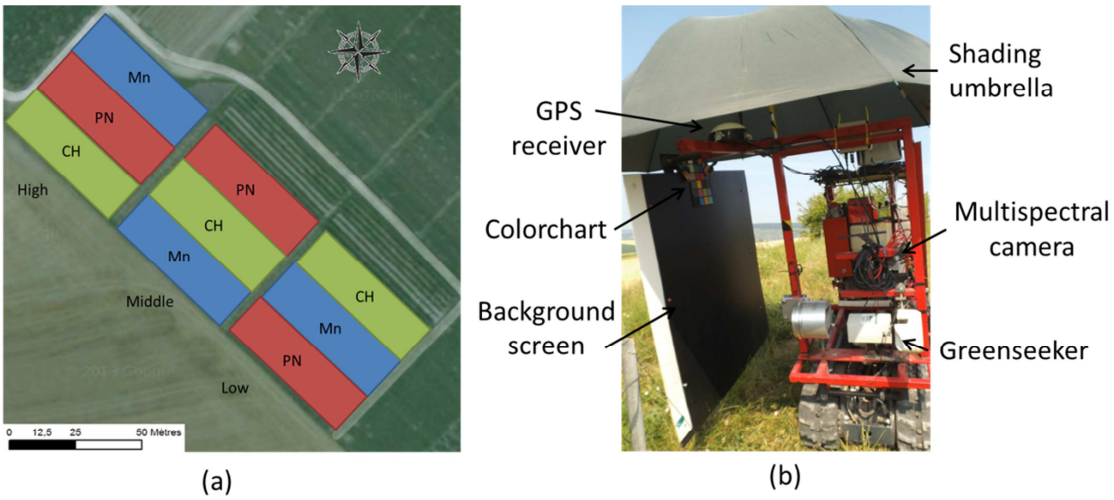


Figure 1: Overall organization of grapevine varieties in the experimental field according to the slope (a) and the synoptic of experimental set-up used to characterize this field (b)

Experimental set-up

A multispectral camera and a Greenseeker RT-100 (Trimble, Germany) were mounted on a track-laying tractor (Figure 1b) which can move between vine rows. Localization was tracked by means of a centimetric level global positioning system (GPS-TRK, Trimble, Germany). Camera, Greenseeker, and GPS were connected to a laptop for data acquisition. Raw data acquisition was continuous. Datasets were registered in 2013, from the beginning of berry formation (July) to the end of the grape ripening (September), and always concerned the same 18 rows in the field. In the present study, only two datasets will be analyzed.

The multispectral camera used was a commercial device AD-130GE (JAI, Japan). It is a prism-based 2-CCD camera which simultaneously captures visible (RGB: Red, Green, Blue) and near-infrared (NIR) images. The short distance between camera and vine foliage required a wide angle lens of 2.8 mm focal length. Resulting images has average dimensions of 902 mm by 670 mm, allowing for the observation of almost the total height of the vine foliage. The image acquisition frequency is 3 Hz corresponding to around 3 images per meter.
Light was partially controlled by means of a shading umbrella and by the automatic adjustment of the sensitivity of the camera before each dataset acquisition. To facilitate the image processing and focus attention on the observed row, we positioned a background screen behind the vegetation.

The Greenseeker acquires data at a high frequency of 50Hz at two wavelengths (R: 660 nm and NIR: 770 nm) and computes a vegetation index called NDVI (Normalized Difference Vegetation Index). Installed at 55cm from the vine foliage, the line scan width is 700 mm by 20 mm. The height of measurement is the same as the images. The Greenseeker was tested in field conditions and according to Kim et al (2012), it provides stable results.

Methods

Geometric calibration of images

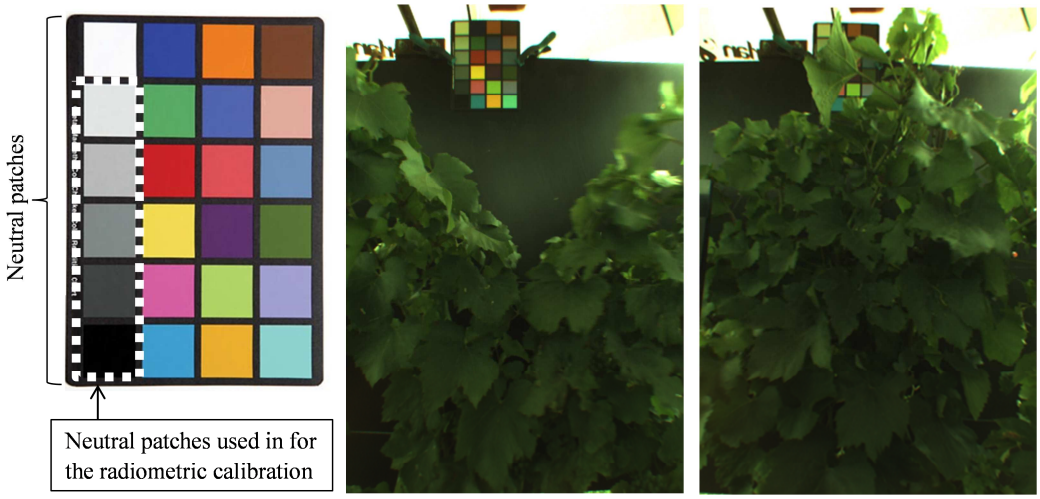
The experimental set-up acquired visible and NIR images of vine foliage in the field and included a prism-based 2-CCD camera with a wide angle lens. This created image distortions which had to be corrected to extract reliable indicators such as NDVI. The Matlab Toolbox, based on the work of Zhang (2000) was thus used to correct geometric distortions.

Development of an adaptive radiometric calibration protocol for each image acquired in the field

The image acquisition is during around one hour in the field that implies lighting variations between images of a same dataset. The changing condition for image acquisition avoid their comparison that is why a radiometric calibration of images in reflectance is necessary, giving access to the physiological status of vegetation (Peñuelas & Filella 1998).
Radiometric calibration was carried out using a color chart (GretagMacbeth ColorChecker®, Figure 2a) as a reference calibrated in reflectance (i.e. theoretical values). Following Mansouri et al (2005), we tested the strength of linear regression between pixel values of each patch read on each image with it theoretical reflectance value. A statistical test of analysis of variance revealed that the exclusion of the white patch improved the radiometric calibration of image in reflectance (Bourgeon et al, 2014).
The pixel values corresponding to neutral patches registered from the images (i.e. experimental values, X) were linked to the theoretical reflectance values (Y) by the equation 1 for each of the four spectral channels ($R^2 > 0.96$). Let I be the set of all the images (~5000 images) included in a dataset. $I = \{I_{WR}, I_{WOR}\}$ where I_{WR} are images "with reference" and I_{WOR} are images "without reference". Let $I_{WR}(t_k)$ be an image "with reference" associated to the timestamp t_k :

$$Y_{channel} = a_{I_{WR}(t_k)} X_{channel} + b_{I_{WR}(t_k)} \quad (1)$$

$\left(a_{I_{WR}(t_k)}, b_{I_{WR}(t_k)}\right)$ are the parameters used to calibrate each spectral channel (RGB and NIR) of each image of the dataset in reflectance. However, in nearly half of all cases, grapevine leaves hid the Macbeth ColorChecker®, creating images "without reference" and thus impossible to calibrate (Figure 2c).



(a) (b) (c)

Figure 2: Presentation of the MacBeth colorchart and its 5 neutral patches considered in the calibration; (a) its position on images acquired in the field where the MacBeth colorchart is visible (b) and where hidden by grapevine leaves (c).

To bypass this problem of calibration for images "without reference", we used inverse distance weighting (IDW) (Atkinson and Lloyd, 2010) to estimate calibration parameters.

Let $I_{WOR}(t_i)$ be an image "without reference" associated with the timestamp t. $I_{WR}(t_k)$ and $I_{WR}(t_{k+1})$ are respectively the previous and the following images "with reference" next to $I_{WOR}(t_i)$, with $t_k < t_i < t_{k+1}$.

According to the IDW method, the estimation of $\left(\hat{a}_{I_{WOR}(t_i)}, \hat{b}_{I_{WOR}(t_i)}\right)$ is based on the values of the parameters $\left(a_{I_{WR}(t_k)}, b_{I_{WR}(t_k)}\right)$ and $\left(a_{I_{WR}(t_{k+1})}, b_{I_{WR}(t_{k+1})}\right)$ of $I_{WR}(t_k)$ and $I_{WR}(t_{k+1})$. We considered the light conditions as similar for these three images acquired over a short time period.

In addition, we used a leave-one out cross-validation method (Picard & Cook, 1984) to assess the interpolation method for the $\left(\hat{a}_{I_{WOR}(t_i)}, \hat{b}_{I_{WOR}(t_i)}\right)$ estimation. Thus, all images of the datasets are calibrated in reflectance.

Definition of vegetation indices

The reflectance of leaves is linked to their physiological status (Peñuelas et al, 1998) and allows for the calculation of a specific vegetation index, the NDVI linked to the quantity of biomass (Johnson, 2003) and used for vine vigor estimation (Drissi et al, 2009) in the field.

Greenseeker calculated the NDVI for each line scanned according to the NDVI formula presented by Rouse et al, (1973).
Concerning the camera, NDVI values were computed from each pixel of the R channel of RGB reflectance images and each pixel of NIR reflectance images, thus creating a new "NDVI image" for each GPS position. We then calculated 2 indices from the"NDVI images":
-"$\overline{NDVI}$" = $\frac{\sum_{p=1}^{Image\ size} NDVI_p}{Image\ size}$, where *I* is a calibrated image and *p* a pixel of *I*;
-"foliage occupation": we determined the percentage of vegetation pixels in each image by processing the image. We used NIR raw images which allowed a reliable discrimination between leaves and background. The result is a binary image where the positive pixel values are classified as leaf and the others are considered as "Background". This is one of the advantages of multispectral imaging use.

Index mapping methodology
The two techniques provided us with vegetation index mapping that we compared two datasets corresponding to two physiological statuses of the grapevine.
The mapping was undertaken using the ordinary kriging method based on georeferencing of data. This method takes into consideration the spatial pattern of data acquisition (i.e. anisotropic data) and gives access to a spatial representation of within-field variability. Moreover, as the distance between images acquired in the field is not regular, this geostatistical method provides a weighting average which considered the measurement point position.

First, the comparison of the two techniques was carried out through by means of NDVI maps obtained for the three grapevine varieties (CH, PN and Mn) at the first leaf physiological status. After a visual comparison, the assessment was based on an analysis of the similitude and the divergence of NDVI results obtained with Greenseeker and with our image device.
The aim of this comparison was to observe the index response according to 1) the grapevine variety and 2) the physiological status of the grapevine. The results of the comparison are presented according to the 9 modalities corresponding to the field blocks, in other words, the three grapevines crossed with the three slope gradients.

Results and discussion

Comparison of NDVI maps
NDVI is a specific vegetation index which allows for the characterization of vine vigor in the field. To assess the capacity of the multispectral imaging system to characterize vineyard foliage, a first index map comparison concerning the three grapevine varieties for the first physiological status was made.
Figure 3 presents a first result concerning the first dataset, acquired at the beginning of berry formation.

The comparison of the NDVI maps obtained with Greenseeker (Figure 3a) and with the imaging system (Figure 3b) shows similar patterns characterized by the same colors of vigor representation whatever the grapevine variety or the block. The observed design associated with "Chardonnay" (CH) and "Pinot Noir" (PN) indicates high vigor (green

areas). In contrast, the “Meunier” (Mn) variety, where areas present low NDVI values seems to indicate less vigor (red and pale areas). These first visual results seem to reveal the similarity of NDVI indices as estimated by the two systems for the first dataset, when foliage is young.

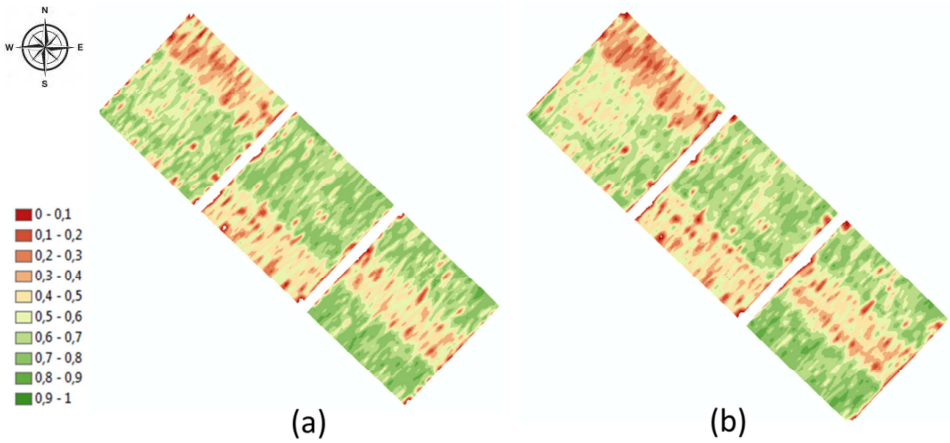


Figure 3: Maps of NDVI provided by Greenseeker RT-100 (a) and by multispectral imaging system (b).

To complete these results, the NDVI values are reported in Table 1 where no significant (NS) differences are noted between the two techniques. Indeed, for the three grapevine varieties (CH, PN and Mn), the average NDVI values calculated, whatever the block, are respectively 0.62 / 0.63 / 0.40 with images and 0.64 / 0.65 / 0.43 with Greenseeker.

Table 1: Means of NDVI calculated for each grape variety, on each block and for both datasets:

		Dataset : berry formation stage					Dataset: end of grape ripening stage				
		Image	Standard deviation	Greenseeker	Standard deviation	Differences	Image	Standard deviation	Greenseeker	Standard deviation	Differences
CH	High	0.56	0.15	0.59	0.14	NS	0.49	0.10	0.63	0.17	NS
	Middle	0.64	0.11	0.65	0.13	NS	0.43	0.10	0.67	0.14	*
	Low	0.64	0.14	0.68	0.14	NS	0.48	0.11	0.72	0.13	*
PN	High	0.57	0.09	0.61	0.10	NS	0.40	0.06	0.60	0.19	*
	Middle	0.62	0.14	0.66	0.14	NS	0.48	0.07	0.65	0.11	*
	Low	0.70	0.09	0.68	0.15	NS	0.55	0.06	0.64	0.17	NS
Mn	High	0.37	0.12	0.40	0.14	NS	0.24	0.04	0.41	0.19	*
	Middle	0.40	0.11	0.41	0.14	NS	0.36	0.09	0.44	0.16	NS
	Low	0.45	0.08	0.46	0.11	NS	0.31	0.05	0.49	0.13	*

We then compared NDVI average indices computed from the images of the dataset acquired at the end of grape ripening. Table 1 shows significant differences between the two techniques. Indeed, for the three grapevine varieties (CH, PN and Mn), the average NDVI values calculated were respectively (0.47 / 0.48 / 0.30 with images and 0.67 / 0.63 / 0.45 with Greenseeker). For this dataset, it seems difficult to correlate the NDVI results obtained from the two systems.

Based on these results (Table 1) and on the results reported by Drissi et al, (2009), we next sought to compare the NDVI values as measured by Greenseeker with the “foliage occupation” index corresponding to the quantity of vegetation calculated on images (Table 2).

Table 2: Means of “foliage occupation” index and Greenseeker NDVI calculated for each grape variety, on each block for dataset corresponding to the end of grape ripening:

Dataset 2: end of the grape ripening stage						
		foliage occupation	Standard deviation	Greenseeker	Standard deviation	Differences
CH	High	0.67	0.10	0.63	0.17	NS
	Middle	0.69	0.12	0.67	0.14	NS
	Low	0.57	0.10	0.72	0.13	NS
PN	High	0.67	0.08	0.60	0.19	NS
	Middle	0.52	0.10	0.65	0.11	NS
	Low	0.73	0.09	0.64	0.17	NS
Mn	High	0.45	0.09	0.41	0.19	NS
	Middle	0.52	0.16	0.44	0.16	NS
	Low	0.59	0.12	0.49	0.13	NS

A comparison of the two vegetation indices calculated by the two methods revealed the similarity of values. Indeed, Greenseeker index is more similar to “foliage occupation” index than $\overline{NDVI}_{\text{image}}$ calculated from image, for this dataset. So, it appears that Greenseeker index seems to mainly express quantitative information than the physiological status of the leaves in this context.

It appears from these results that Greenseeker values are close to $\overline{NDVI}_{\text{image}}$ when the vines are young (berry formation stage). At this formation stage, NDVI value of pixel must be very close to 1 and induce that $\overline{NDVI}_{\text{image}}$ is likely correlated to the VLAI and gap fraction, as Greenseeker NDVI is. For an older canopy when leaves are older and grapes are ripening, Greenseeker values seem to be in agreement with the values of “foliage occupation” index calculated from images. Our image results are coherent with those reported by Drissi et al (2009). Further work is needed to explain the differences observed for NDVI values provided by the two techniques when the canopy is older, and to determine if the multispectral imaging system presented here can be used to improve measurement and characterization of foliage at this stage.

Conclusion

This paper introduces a new proximal multispectral imaging method for grapevine leaf characterization. It was compared to a commercial sensor (Greenseeker RT-100) which is most often used to characterize vine foliage (vigor). This work examined the ability of the multispectral imaging system to characterize vine foliage by means of NDVI or foliage occupation indices. Our multispectral imaging system provided better results than simple RGB in vine foliage characterization thanks to the NIR region, which aids separation between leaves and background and allows computation of the NDVI.
By means of the application reported above we demonstrated: 1) the ability of the imaging system to characterize vine vigor which is at least equivalent to that of the Greenseeker at the beginning of the berry formation, 2) the fact that the imaging system can provide an accurate description of vine foliage through the computation of certain indices. Further works on image analysis will be dedicated to the leaf diseases characterization.

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