Is it relevant to consider remote sensing information for targeted plant monitoring?

Utiliser la télédétection pour positionner les capteurs de suivi des plantes?

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Abstract

An experiment was carried out to test the relevance of using satellite images (NDVI) to define locations of plant monitoring systems. The experiment took place over a 200 ha commercial vineyard located in Navarra (Spain). Airborne images of 30 cm. resolution were processed to compute a biomass index (NDVI). Images were segmented in four classes according to the NDVI pixel values. Each of the zones was assigned a linguistic label: low, medium, high, very high. For each of these zones, punctual information related to plant vigour and plant water deficit were collected during the vine growing period. Plant monitoring systems (dendrometer) and soil monitoring systems (C-probe) were positioned according to NDVI zones. Parameters like Daily growth (DG) and maximum daily shrinkage (MDS) were derived from dendrometers for each NDVI zone. Similarly, soil moisture provided by soil sensors was associated to NDVI zones. Finally, harvest quality was measured.
Data were analysed on a NDVI zone basis. Results confirmed the relevance of NDVI information to highlight zones of different vigour and yield which corresponded, in our conditions, to zones with different water restriction. Results highlighted the difficulty to use NDVI information as a surrogate for harvest quality. This experiment also pointed out the lack of coherence between NDVI zones and information provided by plant and soil monitoring systems. This weak relation may be explained by problems of high variability due to the choice of the plant or the soil location and difficulty to compare values provided by different sensors at the same time.

Keywords: Precision viticulture, NDVI, dendrometry, leaf water potential, *Vitis vinifera* L.

Introduction

Over the last 5 years, many systems have been developed, and adopted by growers, to monitor soil or plant water status. These systems provide useful information with a time resolution level never achieved until now. However, their cost often leads to a small number of plant or soil locations monitored. Therefore, depending on the spatial variability of the vineyards, the location of the sensors remains a big issue, especially to make sure the information provided by the sensors and the resulting decisions suit to the whole vineyard or to a set of blocks.
To overcome this problem, an interesting approach would be to use complementary information that is easily available at a high resolution and that highlights plant spatial variability. Multispectral images, airborne or satellite provided, are one of the most promising information sources to characterize plant variability at whole vineyard scale. The use of airborne imagery has been proved to be an accurate way to map relative differences in vine canopies to characterize grapevine canopy shape and vigour throughout the vineyard (Hall et al, 2002, Lamb et al. 2004, Taylor and Bramley 2004). Since in non-irrigated conditions vigour is strongly related to soil water availability, maps derived from airborne or satellite images could provide relevant information to zone the vineyard according to water restriction (Tisseyre et al. 2007).
Therefore, considering remote sensing images as auxiliary information to determine the location of plant monitoring systems may constitute a relevant approach. This paper reports a preliminary work

which aims at addressing this problem. It reports experiments based on multispectral images that were segmented in four classes according to an index biomass (NDVI). Then, for each of these classes, some punctual information related to plant vigour, yield, soil water content and plant water status were collected during the vine growing period. Harvest quality was also analysed. Four plant monitoring systems (dendrometer) and soil monitoring systems (C-probe) were positioned according to NDVI zones.
These experiments aim at verifying whether it is possible to use high resolution information provided by remote sensing (NDVI) images for a targeted location of plant and soil monitoring systems.

Material and methods

Experiments were carried out in year 2007 on a 200 ha commercial vineyard located in Olite, Southern Navarre, Spain (42°25'4"N, 1°40'48"W, WGS84, 340 m asl), under semiarid climatic conditions.
Multispectral Airborne images of 30 cm. resolution were provided and processed by Geosys–spain company (Leica ADS40 sensor). Images were acquired in August after the vegetation growth stopped. NDVI was computed and zones were defined using a non supervised clustering method. Four NVDI classes were considered and labelled as low, mid, high and very high. Four sampling sites, one per NDVI zone, were then established over the whole vineyard. At each sample site, one plant and soil monitoring station was available. Monitoring stations comprised a capacitance probe (C-probe, AquaSpy Group Pty Ltd, USA) with sensors placed at 10, 30 and 60 cm depths and one dendrometer (PlantSens®, VerdTech Nuevo Campo SA, Spain).

Since most of the vineyard area (140 ha.) is planted of is cv. 'Tempranillo', experiments focused on this variety. For low, mid and high sites, vine fields were 5 years old, grafted on 1103 Paulsen, with a E-W row orientation and a plant spacing of 2.5 x 1.1 m. For very high NDVI site, vine field was 20 years old, grafted on 140 Ruggieri, planted with a N-S row orientation and a plant spacing of 3.0 x 1.4 m.

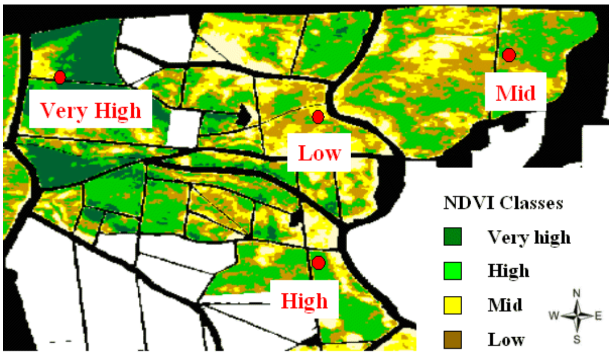

Figure 1 Map of the experiment with the location of the four sites and the NDVI classes

At each selected site, 11 vines were marked as representative and homogeneous according to their trunk cross sectional area (TCSA), measured in early July. Vegetative growth was estimated in late July as the sum of cross-sectional basal area of all the shoots of each vine (SBA). Exposed leaf area (SA) was measured following the method used by Bonnisseau and Dufourcq (2004). At harvest (20^th Sept), cluster number and yield per vine were measured, and basic quality parameters were obtained from three 300 berry samples per site.

Pre-dawn leaf water potential (Ψ_{pd}) was measured weekly from 17th July, using, for each site, at least 5 young healthy leaves that had reached about 2/3 of their definitive weight. Measurements were carried out using a Scholander pressure bomb (P3000, Soil Moisture Corp., Santa Barbara, USA). Leaf sampling was done considering precautions suggested in (Turner, 1988). Water status of each plot was characterized as the mean value of Ψ_{pd} across summer ($\Psi_{pd\text{-}s}$). This value, considering the regularity of measurement frequency, is equivalent to the 'water stress integral' described and has been shown to be a good tool to estimate water status in semiarid vineyards in earlier works (Santesteban and Royo, 2006). From now on, it will be referred as predawn leaf water potential in summer.

At each site, soil water content was monitored every 15 minutes using the capacitance probe, with sensors placed at 10, 30 and 60 cm depths. On behalf of simplicity, those measurements were transformed to a single value of relative soil water content (RSWC), calculating the weighed average of the 3 depths and referring it as a fraction of soil available water. With the same frequency, plant trunk micromorphometric variations were measured in one of the 11 selected vines at each site. From these measurements the maximum daily shrinkage (MDS), the daily growth (DG) were obtained. MDS is defined as the difference between the maximum trunk diameter (reached normally about sunrise) and the minimum trunk diameter (found usually in the afternoon) and DG is the difference between two consecutive daily maximum diameters.
Results were analysed through one-way ANOVA, and differences between treatments established using Duncan’s test. Time series data were analysed with GLM Repeated Measures procedure of SPSS 15.0

Results and Discussion

Correspondence NVDI class and vegetative growth (SBA and SA) and Ψ_{pd}

There is correspondence between NVDI classes and vegetative growth estimations (Table 1), since vineyards with higher NVDI class showed higher SBA and SA values. However, low and mid NVDI classes had relatively similar growth, and also did high and very high classes; being SBA more discriminant than SA. When average predawn leaf water potential values are compared, the same trend can be found, lower NVDI classes corresponding to lower Ψ_{pd} values and with longer periods submitted to mid and severe deficits (Table 2)

NVDI class	SBA (mm^2 $vine^{-1}$)	SA (m^2 $vine^{-1}$)
Low	653 c	2.17 b
Mid	772 bc	2.96 b
High	1169 b	4.31 a
Very high	1796 a	4.78 a
P	*<0.001*	*<0.001*

SBA: shoot basal area; SA: exposed leaf surface area. Means followed by different letters in a each column are
different according to Duncan's multiple range test (P < 0.05)

Table 1 Vegetative growth of each site in mid summer (1st August)

NVDI class	Ψpd-s (MPa)	day no.		
		Ψpd > -0.6Mpa	-0.8 >Ψpd >-0.6Mpa	Ψpd < -0.8Mpa
Low	-0.75 b	11	17	15
Mid	-0.70 b	10	25	8
High	-0.57 ab	38	5	0
Very high	-0.48 a	40	2	0
P	*0.027*			

ﾉ pd-s: average predawn leaf water potential in summer Means followed by different letters in a each column are
different according to Duncan's multiple range test (P < 0.05)

Table 2 Plant water status at each site across summer (from 17th Jul to 8th Sept)

Thus, NVDI has shown to be an interesting tool in order to select the location that sensors have to be located at. NDVI allowed to highlight zones that differed in either vigour, or/and water status. The different sites also showed important differences in fruit load, yield and quality parameters (Table 3), and therefore have to be managed specifically. It would be interesting to compare different vineyard zones showing similar NVDI values, in order to evaluate the representativeness of the sites selected to install sensors.

However, results point out a lack of linear correspondence between NDVI classes and quality parameters. Although some earlier works have shown certain degree of correlation among these variables (Lamb *et al.* 2004, Stamatiadis et al., 2006), a general relation cannot be expected.

NVDI class	Cluster no. vine^{-1}		Yield (kg vine^{-1})		CW (g)		BW (g)		SC (ºBrix)		Trit. Ac. (g TA/L)		pH	
Low	7,12	b	1,16	b	183	ab	1,89	a	22,1	b	4,70	b	3,68	a
Mid	8,62	b	1,45	b	167	b	1,62	b	22,6	b	4,73	b	3,62	a
High	15,75	a	3,87	a	258	a	1,46	b	19,6	c	5,13	ab	3,52	a
Very high	10	b	2,73	a	266	a	1,20	c	25,8	a	5,30	a	3,42	a
	0,002		*<0,001*		*0,048*		*0,001*		*<0,001*		*0,029*		*0,488*	

Table 3 Yield and berry characteristics at each plot at harvest moment (20th September)

Correspondence of NVDI with plant and soil monitoring system

Unlike vegetative growth and plant water status, NVDI classes did not match with observed RSWC values (Table 4). Although lowest RSWC values across summer were recorded in the site that had shown the lowest NVDI and Ψ_{pd}, for the remaining sites there was not a correspondence between soil and plant measurements.

NDVI class	RSWC		day no. RSWC > 0,4	0,4 > RSWC >-0,2	RSWC < 0,2
Low	0.24	d	9	18	25
Mid	0.59	a	32	20	0
High	0.34	c	11	40	1
Very high	0.41	b	24	28	0
P	*<0.001*				

RSWC: relative soil water content Means followed by different letters in a each column are different according to Duncan's multiple range test (P < 0.05)

Table 4 Soil water content at each site across summer (from Jul 17 to Sept 8)

This lack of relation is probably due to differences in the installation of soil probes, since it is difficult to compare values from a probe to another, particularly at stony soils. Besides, their installation has to be performed very carefully in drip-irrigated crops, in order to install all the soil water probes at the same distance from dripper. Under those conditions, soil water measurements may have relevance in order to make irrigation decisions over time, but great care has to be taken whether comparisons between different sites.

Similarly, DG and MDS values derived from dendrometers did not match with NDVI classes (Table 5). This lack of correspondence may be partly explained by installation factors (differences in absolute values between parts of the trunk of the same plant are sometimes observed) and due to the high variability that trunk growth parameters have been reported to have in grapevine (Intrigliolo and Castel, 2007), but may be also due to an inadequate election of the plants dendrometers were installed at. Although dendrometers were installed only in plants whose TCSA was representative of the average values at each site, fruit load parameters were not considered at installation time, and great differences in fruit load expressed as bunch number and, especially, berry number and yield are found when average values and those from the plant monitored are compared (Table 6).

NVDI class	DG (µm)	day no. DG > 0	day no. -30<DG< 0	day no. DG < -30	MDS (µm)		day no. MDS > 150	day no. 100 <MDS < 150	day no. MDS < 100
Low	-3.94	14	14	13	97.5	b	2	21	30
Mid	-2.98	19	14	9	97.1	b	0	13	35
High	-6.03	19	15	12	156.0	a	14	21	10
Very high	-7,53	19	11	12	128.5	ab	12	14	21
P	*0,973*				*<0,001*				

DG: daily growth; MDS: maximum daily shrinkage.Means followed by different letters in a each column are different according to Duncan's multiple range test (P < 0.05)

Table 5 Daily growth (DG) and maximum daily shrinkage (MDS) at each plot across summer (from 17th Jul to Sept 8th)

NVDI class	Bunch no.·vine^{-1} Site	Bunch no.·vine^{-1} Dendr.	Berry no.·vine^{-1} Site	Berry no.·vine^{-1} Dendr.	Yield (kg vine^{-1}) Site	Yield (kg vine^{-1}) Dendr.
Low	7.12 (4.98-9.26)	20	612 (425-799)	1228	1.16 (0.80-1.51)	2.32
Mid	8.62 (7.88-9.37)	9	892 (773-1010)	370	1.45 (1.25-1.64)	0.60
High	15.7 (13.5-18.0)	15	2652 (2013-3291)	3370	3.87 (2.94-4.81)	4.92
Very high	10.0 (8.81-11.18)	13	2275 (1774-2775)	3550	2.73 (2.13-3.33)	4.26

For each variable, site average and its confidence interval at 75% is shown (between brackets)

Table 6 Comparison of bunch number, berry number and yield from average of each plot and of the vine at which the dendrometer was installed.

Conclusions

NVDI classes derived from multispectral airborne imagery have been shown to be efficient to detect zones that differ in either vegetative growth, water status or in both. Using NDVI information as surrogate information to design zones of different water restriction may be very relevant. Unfortunately, results highlighted the difficulty to use NDVI information as an indicator of harvest quality. This experiment also pointed out the lack of relation between NDVI zones and information provided by plant and soil monitoring systems. This result may be a least partially explained by problems of high variability, due to the choice of the plant or the soil location, and the difficulty to compare values provided by different sensors in different location at the same time. Considering that the installation of plant sensors is not cheap, great care has to be paid to the choice of the vine at which they are located. According to our result, NDVI zones should constitute a relevant information source to choose the location of plant and soil monitoring systems. However, once the installation zones have been defined, highest attention has to be paid to select at which plants sensors are going to be installed since a problem of lack of representativeness may arise. In our opinion additional information like trunk cross sectional area (TCSA), shoot development and bunch/berry no. should be locally considered to define the best plant.

Acknowledgements

These results are part of ECOSAT project, funded by Verdtech Nuevo Campo SA, Fundación Caja Rural and WWF Adena. Thanks are also due to all the staff at Pagos de Araiz, particularly to Michel Murua, for their kindness and to Fundación Fuentes Dutor for their economical support of part of this research

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