USING MULTIPLEX® AND GREENSEEKER™ TO MANAGE SPATIAL VARIATION OF VINE VIGOR IN CHAMPAGNE

S. Debuisson, C. Germain, O. Garcia, L. Panigai and D. Moncomble

Comité Interprofessionnel du Vin de Champagne (CIVC)
5, rue Henri-Martin, boîte postale 135, Epernay, France

M. Le Moigne, E. M. Fadaili and S. Evain

Force-A
Université Paris Sud, Bât 503, Orsay, France

Z.G. Cerovic

Laboratoire Ecologie Systématique et Evolution, CNRS, UMR 8079
Université Paris Sud, Bât 362, Orsay, France

ABSTRACT

Vine vigor is an indicator for vineyard heterogeneity. Patterns identification of spatial variations will be determinant for technicians to understand the effects of soil, climate and topography and to establish decision rules. These decision rules will be useful to winegrowers to succeed in homogenizing the vigor within a block. The determination of variations patterns could indeed lead to adapt input management, differential winter pruning, or timing and rate of fertilizer. Moreover, a relationship was demonstrated between vine vigor and grape quality: patterns of low vigor match patterns of higher grape quality. The aim of the present study was to embed two optical sensors, Multiplex® and GreenSeeker™, coupled with a RTK dGPS on a single tractor to define variation patterns in vine vigor. These measures were done in Plumecoq, an experimental vineyards for the CIVC in Champagne. Porosity index of both devices were satisfyingly correlated. Moreover, Multiplex® gave complementary information such as the leaf chlorophyll content (SFR index), the flavonol content (FLAV) and a Nitrogen Balance Index (NBI).

Keywords: vine vigor, porosity, nitrogen status, spatial variability, yield

INTRODUCTION

Vine vigor is an important criterion to characterize plant vegetative expression. It is defined by the vegetative biomass annually produced. An excessive vigor is not recommended for vine as it will increase disease sensitivity and dilution of grape components during ripening. Variations patterns identification can be useful to homogenize within a block the vine vigor, adapting input management and grape quality at harvest. Several grape quality attributes are indeed determinant: yield, ripening parameters, nitrogen content and grape acidity at harvest. It can be useful for winegrowers to have vegetation indices which can be linked to these quality descriptors to adapt their farming practices.

Until now, the classical descriptors of vine vigor were leaf area and pruning weights. Unfortunately, both measurements are time consuming and can be ran only with a low spatial resolution. Through optical measurements, several vegetation indices are recently used in precision agriculture to produce quickly vigor maps: Normalized Difference Vegetation Index (NDVI) is the most commonly used. This spectral vegetation index underlines the existing contrast between vine biomass when measured in different wavelengths. Healthy, vigorous, biomass is characterized by a strong near-infrared reflectance and a very low red reflectance due to chlorophyll absorption. NDVI has recently been shown to correlate with measures of canopy leaf area (Johnson, 2003, Goutouly, 2006, Debuisson, 2009) and pruning weights (Dobrowski et al., 2003; Profitt and Malcom, 2005). More precisely, NDVI delivered by GreenSeeker® sensor, used on the ground in a side view orientation is mainly sensitive to the variations of foliage porosity (Goutouly, 2006, Debuisson, 2009).

Multiplex® is a new hand-held multi-parameter sensor developed in 2007. It provides individual fluorescence signals to evaluate the foliage porosity, to assess the chlorophyll content and a Nitrogen Balance Index (NBI). NBI has been indeed shown to respond to nitrogen nutrition of the plant (Cartelat et al., 2005). Multiplex appears to be adapted for the vine vigor measurement. Moreover, it allows a multi-parametric measurement, non-invasive and rapid. Until now, Multiplex had not yet been embedded on a tractor for the vine industry.

The aim of the present study was to embed two optical sensors, Multiplex® and GreenSeeker™, coupled with a RTK dGPS on a single tractor to determine patterns of variation in vine vigor. The foliage porosity indices of both sensor are compared and the relevance of other Multiplex indices studied: the chlorophyll content, the flavonol content and the nitrogen balance index. Finally, the relationships between some viticultural descriptors and sensor indices were investigated.

MATERIALS AND METHODS

Experimental field

Champagne is the wine region located in the North East of France which produces the famous sparkling wine called Champagne. The interests of Champagne are defended by the Champagne committee, an organization funded by the growers and houses of Champagne under the aegis of French Government. Plumecoq estate is an experimental vineyard of 10 hectares belonging to the Champagne committee (Table 1). All measures in this article were performed on a plot of this estate (Figure 1).

Figure 1. Presentation of Plumecoq block

Table 1. Characteristics of Plumecoq block

Name	PLQ-865-n	PLQ-743-n	PLQ-76-n
Cultivar	Meunier	Pinot noir	Chardonnay
Clone	865	743	76
Rootstock		41B	
Planting year		1996	
Pruning method		Chablis with three branch	
Distance between row and vine		110 cm x 120 cm	
Trim height and width		127 cm x 40 cm	

This plot was planted in 1996 with a latin square pattern to minimize the effect of soil and micro-climate. Its total area is 0.72 hectare. The three Champagne cultivars (Pinot Noir, Meunier and Chardonnay) are planted over three blocks, which represents nine micro-plots of 0.08 hectares. These 3 blocks will be called later in the article "high", "middle" and "low" depending on their position on the hill (Figure 1). Farming methods are identical and homogeneous since the planting year. This particular plot has been used for several years by Champagne technicians as an experimental field for vine physiology monitoring. Several descriptors related to the terroir were measured. Soil analysis were performed over a grid of 270 points. Thanks to depth measures, useful waterstock (RU) and easily usable waterstock (RFU) were calculated. Moreover, elevation (Topo) and plot resistivity were precisely defined and mapped using RTK dGPS. The topographic wetness index (TWI) was then calculated and mapped. It is commonly used to quantify topographic control on hydrological processes and to describe wetness conditions at the catchment scale. Other descriptors related to the vine agronomical behavior are also acquired regularly on an annual basis. These descriptors are phenological stages, predawn leaf water potential, main ripening descriptors, yield mean, and pruning weight mean.

Viticultural measurements

Several canopy parameters were acquired on the experimental plot. In 2009, some descriptors were evaluated such as Total Leaf Area measures (TLA), crop yield, and pruning weights. TLA was evaluated from budburst to early veraison. Main ripening parameters were measured on berry samples just before harvest. Chemical determination of Total nitrogen and NH_4 were done on grape juice. Yield were done manually at harvest time on the 270 sub-plots areas, as defined above. Prunings were weighed in March 2010 and means calculated over an even larger grid of 27 plots.

In 2009, the leaf surface measures were performed with a frequency related to vine growth (Figure 2). The GreenSeeker has been used regularly from first leaf stage until harvest. Measures frequency was less regular because of technical failures. In 2009, Multiplex has been embedded on caterpillar for the first time for large scale measures. We chose to use it at flowering. Indeed, it is a key stage for crop quality and yield determination. Moreover, this stage matches a maximum NDVI variability.

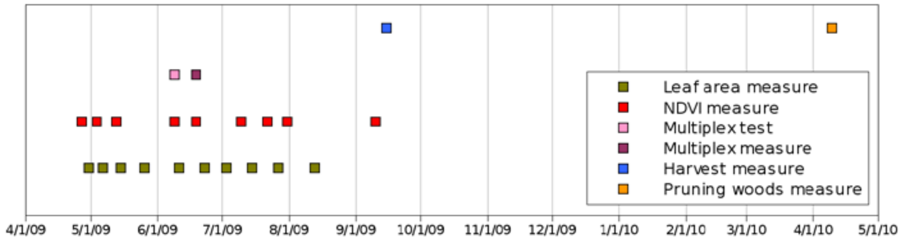


Figure 2. 2009 measurements

Multiplex measurements

Multiplex2 (FORCE-A, Orsay, France) is a hand-held multi-parametric fluorescence sensor dedicated to work in the field under daylight on leaves, fruits and vegetables (Figure 3). The measuring principle of Multiplex® is based on the chlorophyll fluorescence screening method (Agati et al., 2007, Cerovic et al., 2008). The method is valid on leaves (Kolb, 2005) and fruits (Kolb et al., 2003; Agati et al., 2007) using either UV light for flavonols (FLAV) or visible light for anthocyanins (ANTH). A visible beam for which the epidermis is transparent, is used as a reference (Agati et al., 2007). The present version of the sensor has six LED-matrices light sources, 375 nm UV-A (UV), and three Red-Blue-Green LED-matrices (RGB) emitting light at 470 nm (blue, B), 516 nm (green, G) and 625 nm (red, R). There are three synchronized detectors for fluorescence recording: yellow (YF), red (RF) and far-red (FRF), based on three 20 x 20 mm silicone photodiodes. The sensor provides hence twelve individual signals: 4 excitation x 3 emission (Table 2). From these individual signals, several indices have been developed: FERARI for foliage porosity, FLAV for flavonol content, ANTH, SFR_R and SFR_G for chlorophyll content, NBI_R and NBI_G for nitrogen status estimation. The sensor illuminates an 8 cm diameter surface at a 10 cm distance from the sources.

Figure 3. The Multiplex2 sensor. A) Measurement in the field. B) Top view of the sensor showing the touch-screen interface and triggering button. C) Front view of the optical head with LED sources and three detectors in the middle.

Table 2. Description of the indices provided by the Multiplex2

Multiplex index	Emission	Excitation	Formula
YF_UV	Yellow fluorescence	UV	
RF_UV	Red fluorescence	UV	
FRF_UV	Far-Red fluorescence	UV	
YF_B	Yellow fluorescence	B	
RF_B	Red fluorescence	B	
FRF_B	Far-Red fluorescence	B	
YF_G	Reflected Yellow light	G	
RF_G	Red fluorescence	G	
FRF_G	Far-Red fluorescence	G	
YF_R	Reflected Yellow light	R	
RF_R	Red fluorescence	R	
FRF_R	Far-Red fluorescence	R	
SFR_G	Simple fluorescence ratio	G	FRF_G/RF_G
SFR_R	Simple fluorescence ratio	R	FRF_R/RF_R
FLAV	Flavonols		Log(FRF_R/FRF_UV)
ANTH	Anthocyanins		Log(FRF_R/FRF_G)
FERARI	Fluorescence excitation ratio		Log(5000/FRF_R)
NBI_G	Nitrogen balance index		FRF_UV/RF_G
NBI_R	Nitrogen balance index		FRF_UV/RF_R

GreenSeeker measurements

GreenSeeker® (N-Tech, USA) is an integrated optical sensing system that measures the Normalized Difference Vegetative Index (NDVI). GreenSeeker sensor uses light emitting diodes (LED) to generate red and near infrared (NIR) light. The light generated is reflected off the crop and measured by a photodiode located at the front of the sensor head. NDVI is calculated according to the following equation: (NIR - RED)/ (NIR + RED) (Rouse et al., 1974). NDVI can vary between -1 and 1. A value of 1 represents a maximum coverage of surface by vegetation. The value 0 represents an absence of vegetation if the background color measured by the sensor is a perfect white. In the vineyards, we use a white board positioned behind the row measured. Thus, the sensor GreenSeeker values vary between 0 and 1 depending on foliage porosity and leaves chlorophyll content.

Multiplex2 and GreenSeeker set-up on a caterpillar

GreenSeeker and Multiplex2 were embedded on a small caterpillar (NIKO HY30). GreenSeeker distance from the vine row and height from the ground were both 80 cm. Foliage height measured by GreenSeeker is 70 cm. A board is positioned behind the vine row to avoid all unwanted measures on the next row. This board is painted with a true white color (Figure 4). Thus, GreenSeeker measures a null value outside the vines. Multiplex2 is operating at 10 cm from the target with a small optimal depth of field (approximately 2 cm). For a correct measurement, Multiplex2 needs to be as close as possible from the vine foliage, whatever may be the position of the caterpillar in the vineyard. As it is difficult to drive straight in a range of 2 cm in vineyard, Multiplex2 was mounted behind an adjustable polyethylene board, which was fixed to the caterpillar with a parallelogram frame. With this arrangement, the board can ride on the vine foliage and allows Multiplex2 to always measure vine row at the same distance (Figure 4).

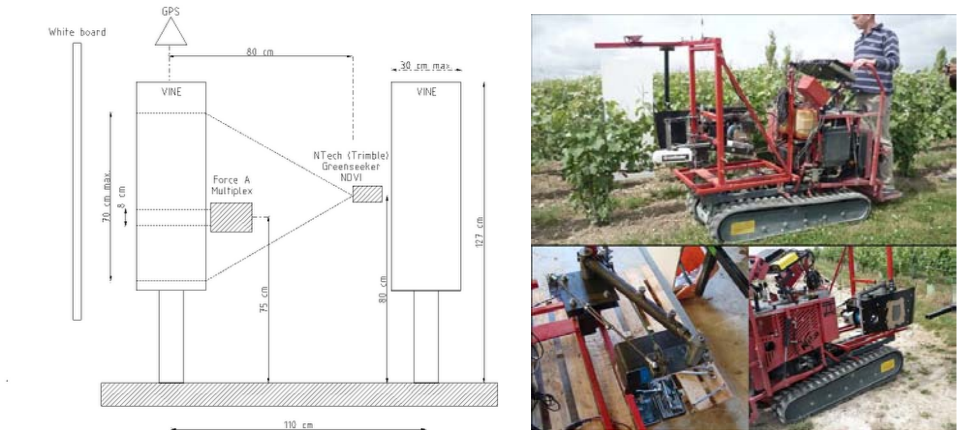


Figure 4. A) Multiplex2 and GreenSeeker set-up. B) Parallelogram on caterpillar frame and complete assembly with GreenSeeker and Multiplex2 operating.

Both sensors are connected to a GPS (Trimble Ag332) with a real time correction RTK-VRS. The GPS antenna is positioned just above the vines row. The relative and absolute accuracy of position is less than 2.5 cm. GPS data acquisition frequency was 10 hertz. This frequency allows to have a georeferenced point every 10 to 14 cm on a vine row when the caterpillar drives at a speed of 4 to 5 km/h. Sensors data are synchronized with the GPS NMEA sentence. There is one GPS position for several Multiplex2 and NDVI data depending on the frequency of sensor measures. The resulting file is saved on a laptop hard-disk set on the carterpillar. On the experimental plot, 86 000 NMEA sentences were recorded.

Multiplex2 and GreenSeeker frequencies are respectively 760 and 50 hertz. For each NMEA sentence, 76 Multiplex2 and 5 GreenSeeker data are available: we have hence collected in this study respectively one measure every 0.15 cm and 2.2 cm. First processing on Multiplex2 data consisted in denoising signals using wavelets decomposition to delete the high signal frequency (Mallat, 1989). Multiplex2 and GreenSeeker data are finally averaged per NMEA sentence in order to have a same data structure.

Structure of data set

In order to match agronomical data resolution to high resolution sensor data, the experimental blocks were divided into 270 sub-plots corresponding to the area occupied by 20 vines each (4 vines in 5 rows = 4.8 x 5.5 m) (Figure 5). The Quality matrix (Q-matrix) had 216 rows x 6 columns, were rows represented sub-plots positions and columns 6 “quality” descriptors: yields, resistivity, TWI, RU, RFU and topography. The initial GreenSeeker matrix had 86 000 rows x 1 column where rows represented the NMEA sentences and the column NDVI values.

Multiplex2 matrix had 86 000 rows x 19 columns where rows represented again NMEA sentences and columns the 12 individual signals and 7 calculated indices. Data of both sensors were reduces to 270 sub-plots. Because of erratic measurement occurring at the borders of blocks, 54 border sub-plots (red areas in Figure 5) were discarded. The final sensors matrix (S-matrix) had 216 rows x 20 columns, with rows representing sub-plot positions and columns NDVI and Multiplex2 averaged values.

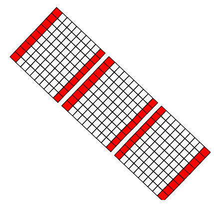


Figure 5. Sub-plots on Plumecoq block

Statistical analysis

Principal Components Analysis (PCA) was used to investigate the possible relations between NDVI and Multiplex indices on the S-matrix. PCA converted original variables into new axes or principal components (PCs), that are orthogonal. Therefore, PCA expressed the total variation in the data set in only a few PCs. The comparison of means between high, medium and low blocks was performed using a one-way ANOVA. Multiplex2 and GreenSeeker data were mapped using 3 software: R, Quantum GIS and Saga GIS. Ordinary krigging was used for data interpolation.

RESULTS AND DISCUSSION

GreenSeeker results

Relationship between NDVI and TLA

Used in a side view on vine row, NDVI is directly related to the foliage porosity (Goutouly et al., 2006). On a regular vine, chlorophyll content of leaves does not influence the GreenSeeker value. Leaves should be strongly deficient in chlorophyll in order to observe a significant drop of NDVI (Figure 6). In Plumecoq plot, average Chlorophyll Content Meter (Opti-Sciences, CCM 200) readings were always greater than 18 within each block.

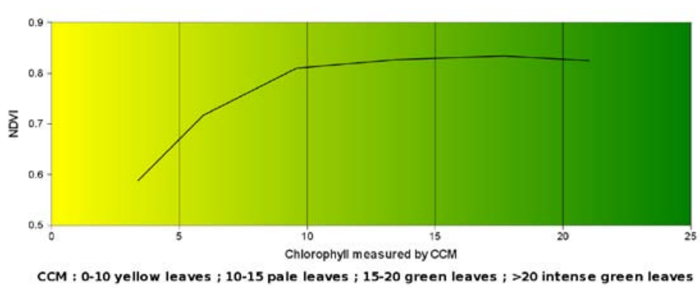


Figure 6. Evolution of NDVI related to chlorophyll content

Because vines are narrow, the tested hypothesis is a strong relationship between the decrease in vertical porosity and the increase in Total Leaf Area (TLA). In 2008 and 2009, each NDVI recording was coupled with a measure of leaf area according to a protocol inspired on the Carbonneau method (Carbonneau, 1996). Buds number varies depending on the year. To compare years, we referred to the leaf area per cane instead of the global vines leaf area.

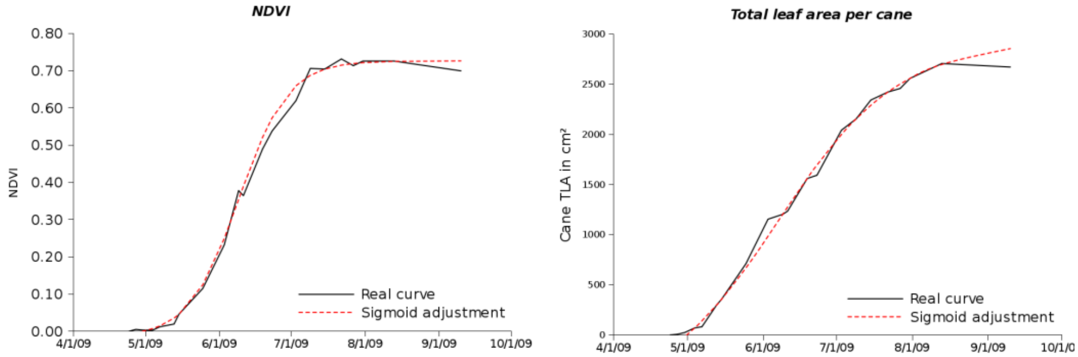


Figure 7. Evolution of NDVI and TLA during the growing season in 2009

Whatever the cultivar and the year, curves of NDVI and TLA evolve similarly with time (Figure 7). The shape of both curves is a sigmoid modeled by a boltzmann equation. Regarding NDVI, the maximum of variability is reached when the curve is close to the inflection point, that is at a value between 0.4 and 0.5 depending on the year (Figure 7). This inflection point matches the flowering period. It is a critical stage for yield and wine quality. The relation between NDVI and TLA is linear but there is a rupture when NDVI reaches a value between 0.35 and 0.40 (Figure 8). It corresponds to the first vine trimming. Leaves growth is indeed natural before the trimming, after that, cultural practices modified it. It is possible to observe a beginning of saturation of the GreenSeeker index at the end of growing season. TLA grows faster than the decrease of porosity when the hedge is fully filled.

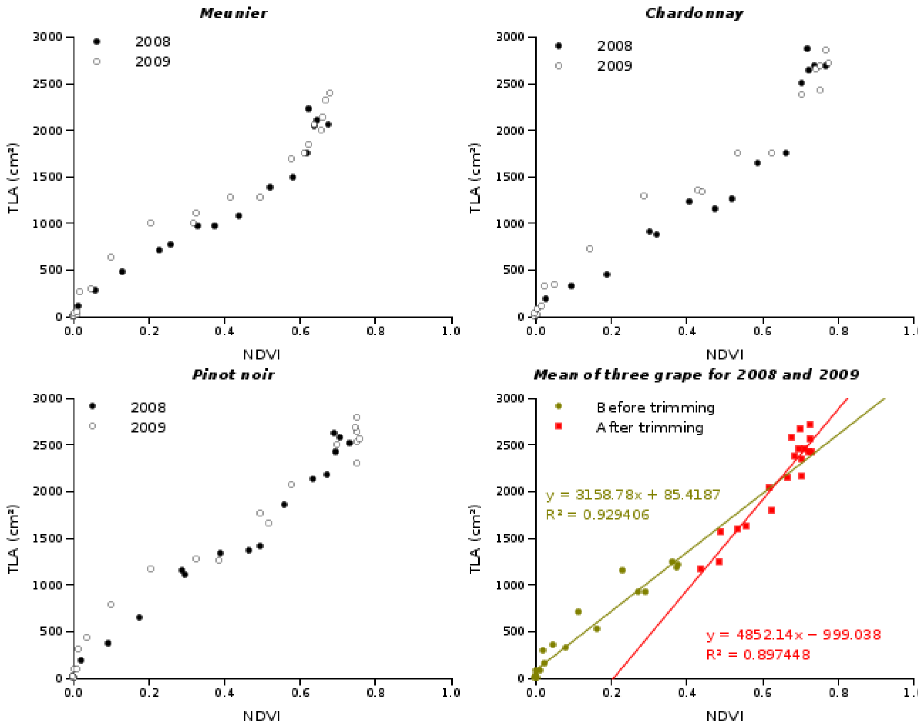


Figure 8. Relationship between NDVI and Total Leaf Area per cane.

Plumecoq NDVI maps

Considering NDVI and TLA are highly correlated in Champagne, NDVI can map directly leaf area variation. All maps have been produced from sub-plots means. The map shows a significant cultivar effect. The leaf area varies from about 15 % between areas with a strong and small vigor. In 2008, these variations could reach 30%. However, the differences of NDVI between cultivars mask variations related to soil and climate. To avoid the cultivar effect, NDVI value were divided by the NDVI mean for the whole surface covered by the cultivar. Thus, this map is no longer a TLA map but a potential vigor map (Figure 10b). This map shows interractions between soil, micro-climate and vine, regardless the cultivar.

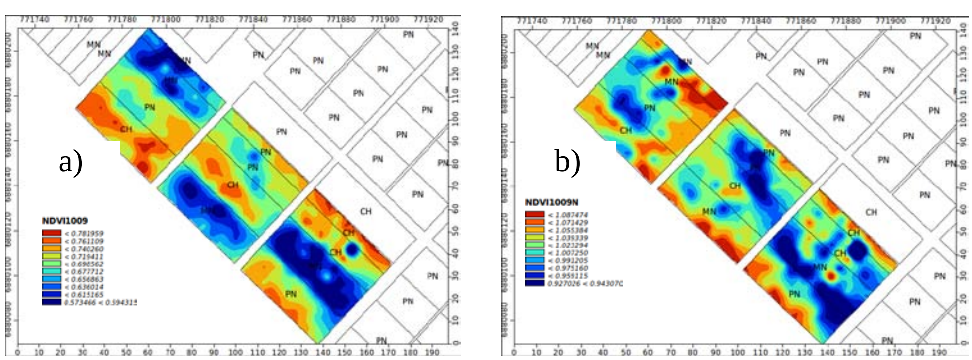


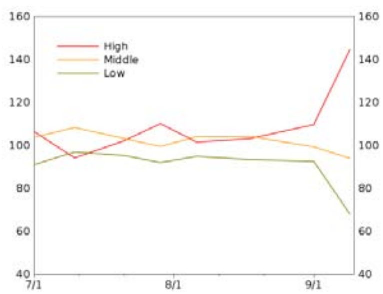
Figure 10. NDVI maps on Plumecoq: a) raw data and b) normalized data

Relationship between NDVI and viticultural descriptors

Usually, the upper block is less vigorous than middle and low blocks. This difference is explained by a higher water stress on the upper zone. In 2009, rains have been very regular until August. A moderate stress, measured by predawn leaf water potential, appeared only at the end of the growing season, and particularly in the upper zone (Figure 9). Unlike 2008, this stress had no influence on yield and ripening of grape berries between blocks (Table 3). Pruning weight is an integrative measure for vine behavior over the previous years, whereas leaf area is a valid measure for the current year. Pruning weight shows significant differences between high, middle and low block, according to our knowledge over several years of this block behavior. These differences are not highlighted by NDVI measurements in 2009. NDVI by GreenSeeker is an interesting measure for short-term management of vigor but vine is a perennial plant. Areas of management should be considered for several years. Knowledge of NDVI measured by GreenSeeker is not sufficient for a long-term management. For this reason, we decided to embed a more powerful sensor like Multiplex2, to study and understand more precisely vigor patterns.

Table 3. Characteristics of some viticultural parameters on each block

	2009 Yield (kg/ha)	**NDVI 2009/06/19**	**2008 yield (kg/ha)**	**NDVI 2008/06/11**	**Pruning wts. (kg/row)**	**2009 Total N (mg/L)**	**2009 NH_4 (mg/L)**
high	17576	0.484	14100	0.402	9.85	101	20.5
middle	17533	0.487	17500	0.440	12.09	122	28.5
low	17690	0.496	19700	0.465	12.98	147	31.7



Average predawn leaf water potential of each block is represented compared to the average for the whole plot centered on 100. This figure illustrates the different behavior in early September between the three different blocks. Water stress is twice as high in the upper block than in the lower block.

Figure 9. Predawn leaf water potential by blocks (Base 100)

Multiplex results

Correlations between all optical indices

To investigate the relations between sensor indices, PCA was performed on the S-matrix. The first two principal components of PCA accounted for 71.5% of the total sum of squares and are mainly described by Multiplex2 indices (Figure 11a). NDVI is not well represented on these components but is opposed to FERARI index. A relationship between both indices of foliage porosity is demonstrated and provides validation for Multiplex2 and GreenSeeker set-up on the caterpillar. However, in this analysis, the cultivar effect is overemphasized. The sensor indices were therefore normalized for each cultivar to mitigate cultivar effect. The first two principal components represented respectively 58% and 21.3% of the total variance (Figure 11). The first component is well correlated to NDVI and

Multiplex indices. Thanks to this data transformation, a better relationship appears between NDVI and FERARI. Moreover, NDVI is also correlated to leaf chlorophyll content indices (SFR_R and SFR_G). The second component is mainly described by the index of nitrogen status NBI_R which is orthogonal to NDVI. The NBI_R index seems to provide additional information and shall be compared to field observations.

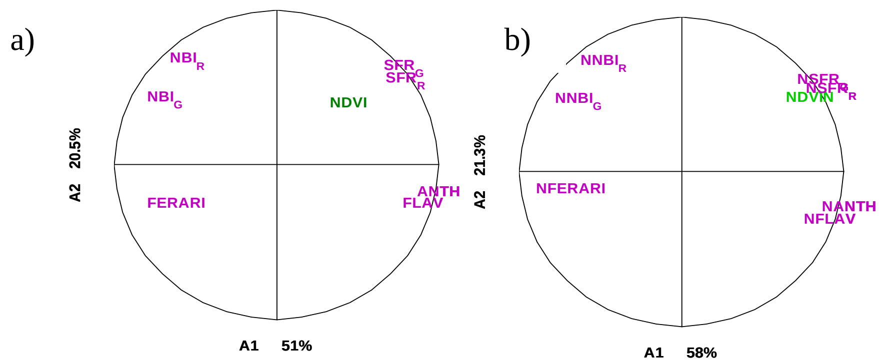
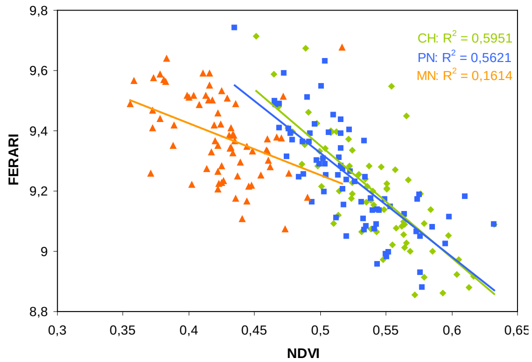


Figure 11. PCA correlation plot on S-matrix (a) and on normalized sensor indices (b) in the plane defined by principal components 1 and 2

Relation between NDVI and FERARI

The relationship between NDVI and FERARI was more precisely investigated on the 216 sub-plots (Figure 12). For Chardonnay and Pinot noir, high determination coefficients were obtained between NDVI and FERARI: 0.59 and 0.56. Slopes obtained for both varieties are nearly the same. For Meunier, FERARI is significantly correlated with NDVI. However, the determination coefficient is low (0.16), and the slope is different compared to Chardonnay and Pinot noir. This cultivar had a different behaviour compared to Chardonnay and Pinot Noir in terms of yield and foliar surface. Moreover, GreenSeeker and Multiplex do not measure the same area of the canopy. Multiplex measured at the level of the grapes whereas GreenSeeker measured all leaves up to the height of 70 cm.



b)

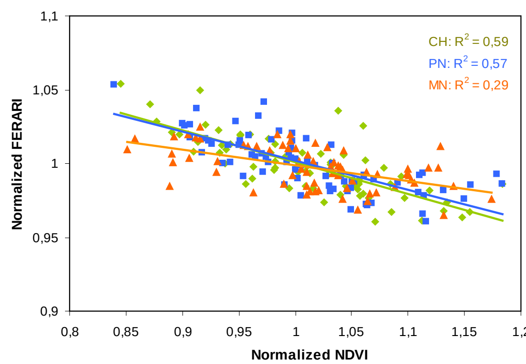
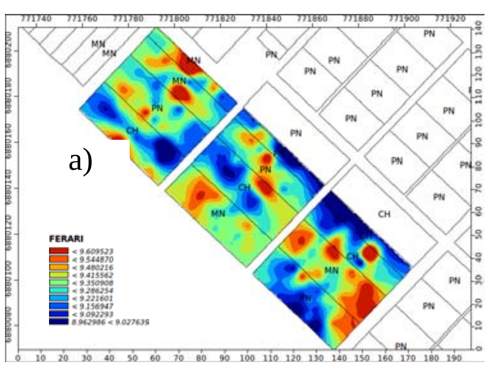


Figure 12. Relation between NDVI and FERARI: a) raw data b) normalized data

To avoid cultivar effect, the relation between NDVI and FERARI was studied on normalized data by cultivar. The slope of Meunier is now nearly the same as the two other cultivars (Figure 12b).



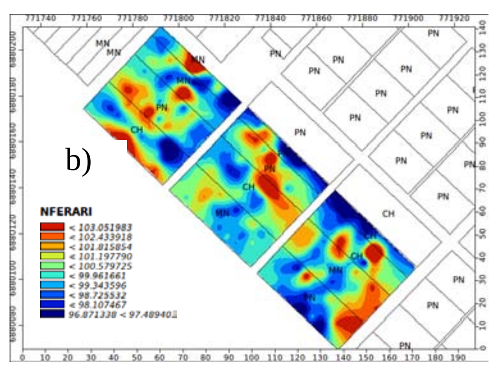


Figure 13. FERARI maps on Plumecoq: a) raw data b) normalized data

FERARI maps obtained at Plumecoq are presented in Figure 13. As expected, the same variation patterns are observed as on NDVI maps. Raw data for Chardonnay show lower values of FERARI corresponding to low foliage porosity. On the contrary, the Meunier foliage had high value of FERARI corresponding to high porosity. On normalized data, cultivar effect is avoided. So, two large spatial structures with higher FERARI values (the north part of high block and a stretch crossing the middle and low block from north to south-east, Figure 13b) matched the same structures of low NDVI in Figure 10b. However, optical data were recorded at flowering. Many events occurred between this stage and harvest. It would be interesting to measure the Multiplex indices at harvest to determine if the sensor indices are then better correlated with the yield.

Relationship between viticultural descriptors and sensor indices

On the 216 sub-plots, Pearson correlation coefficients were determined between quality descriptors and sensor indices (Table 4). Best correlations with yield were obtained for NDVI-N, NFERARI, NNBI_G, SFR_G, SFR_R, ANTH and NANTH. A combination of these optical indices could be interesting to explain the yield. However, optical measurements were recorded at flowering, so all the events occurring until harvest were not taken into account. Depending on climate conditions, yield potential can be more or less expressed. 2009 campaign was characterized by regular rainfalls. Usually, the yield is different according to the high, middle and low blocks. However, in 2009, no differences appeared probably due to the climate.

Soil apparent resistivity was best correlated with NBI_G (raw and normalized). TWI and TOPO indices showed best correlation with the nitrogen balance index (NBI_G and NBI_R). However, these relationships can be the result of indirect effects : on the high block, TWI is low, matching with low value of NDVI. However, in 2009, RU and RFU had low correlation coefficients with sensor indices.

Finally, NDVI index is best correlated to the yield but Multiplex indices are both linked to yield and to other quality descriptors like resistivity, TWI and Topo. A combination of GreenSeeker and Multiplex2 indices recorded at different key stages, flowering, veraison and harvest, could be useful to predict more precisely the yield.

Table 4. Pearson correlation coefficients between quality descriptors and sensor indices on the 216 sub-plots (non significant if $r < 0.14$) *(N for normalized data)*

	Yield	***Resistivity***	***TWI***	***RU***	***RFU***	***Topo***
NDVI_1906	*0.20*	*0.18*	*ns*	*ns*	*ns*	*ns*
NDVI1906N	***0.51***	*ns*	*0.29*	*ns*	*ns*	*-0.26*
FERARI	*-0.30*	*ns*	*ns*	*ns*	*ns*	*ns*
NFERARI	***-0.38***	*ns*	*-0.14*	*0.17*	*0.19*	*ns*
FLAV	*0.17*	*ns*	*-0.22*	*-0.20*	*-0.21*	*0.23*
NFLAV	*0.17*	*0.12*	*-0.24*	*-0.19*	*-0.19*	*0.24*
SFR_G	***0.31***	*ns*	*0.25*	*ns*	*ns*	*-0.23*
NSFR_G	*0.28*	*ns*	*0.26*	*ns*	*ns*	*-0.22*
SFR_R	***0.30***	*-0.19*	*0.19*	*-0.19*	*-0.20*	*-0.29*
NSFR_R	*0.25*	*-0.14*	*0.21*	*-0.15*	*-0.16*	*-0.29*
ANTH	***0.30***	*ns*	*ns*	*-0.24*	*-0.23*	*ns*
NANTH	***0.30***	*ns*	*ns*	*-0.22*	*-0.21*	*ns*
NBI_G	*-0.28*	***-0.34***	***0.35***	*ns*	*0.14*	***-0.43***
NNBI_G	***-0.34***	***-0.33***	***0.40***	*0.15*	*0.16*	***-0.44***
NBI_R	*-0.20*	*ns*	***0.42***	*0.24*	*0.24*	***-0.39***
NNBI_R	*-0.23*	*ns*	***0.48***	*0.25*	*0.25*	***-0.41***

Other Multiplex maps on Plumecoq

Maps of two different indices related to chlorophyll content were compared in Plumecoq to test their robustness (Figure 14). ANTH index should be inversely proportional to chlorophyll content on leaves, in the absence of anthocyanins. On the opposite, SFR_R and SFR_G increase with leave chlorophyll content. ANTH is less sensitive to variable chlorophyll fluorescence that might be an interference to Multiplex measurements, but it has a smaller range of variation than SFRs. ANTH and SFR were quite different (Figure 14). ANTH did not discriminate the three blocks contrary to SFR_R. The low block presents higher chlorophyll content in leaves than the two other blocks. These results can be linked to those of pruning weights and nitrogen status in grape juice (Table 3), whereas NDVI or FERARI did not reveal block differences in 2009. Some Multiplex indices succeeded in discriminating the blocks: SFR_R but also FLAV and NBI (Table 5). They take into account the vine vigor of the previous years. NDVI index is indeed only sensitive in Champagne to foliage porosity whereas the Multiplex2 SFR ratios give information on leave chlorophyll content.

Table 5. Multiplex indices between high, medium and low blocks

	FLAV	ANTH	NBI_G	NBI_R	SFR_R
High	1.261 a	0.351 a	1.327 a	1.745 a	1.666 b
Medium	1.202 b	0.345 a	1.391 b	1.829 b	1.665 b
Low	1.185 b	0.342 a	1.416 b	1.870 b	1.711 a

FLAV index is the R to UV excitation ratio of far-red chlorophyll fluorescence that is proportional to the flavonol content of the leaf epidermis. FLAV is very sensitive to sun exposure and to nitrogen deficiency. FLAV map allows to identify a pattern on the high block. NBI indices are excitation-emission ratios that depend both on epidermal phenolics and chlorophyll. The use of both components allows to have a more sensitive to nitrogen deficiency detection. The same pattern on the high block was identified and matches with low NBI value corresponding to potential nitrogen deficiency (Tables 3 and 5). These results are encouraging, for this area is well known for its nitrogen deficiency. These values also match the gradient of pruning weights.

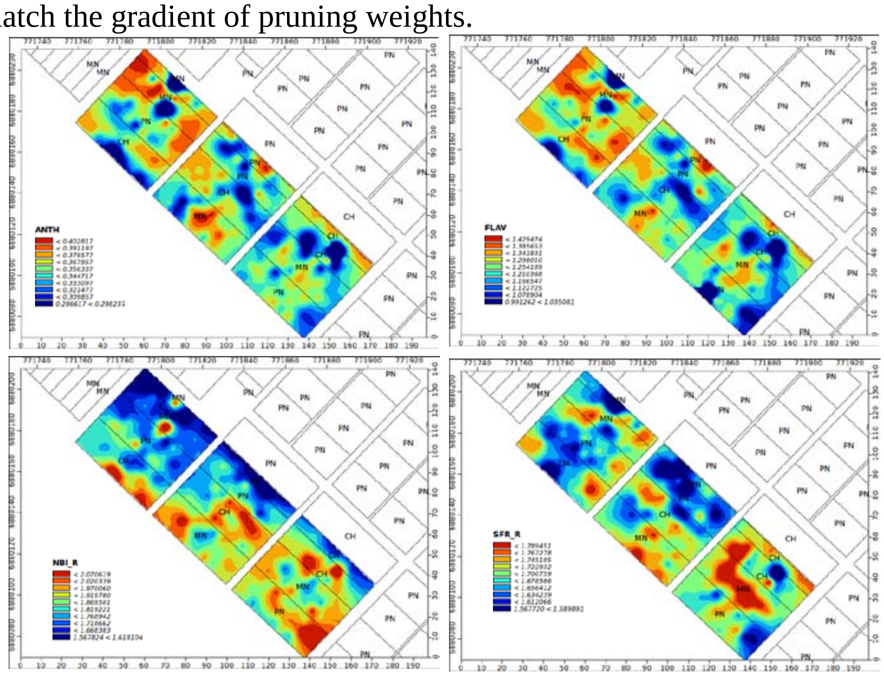


Figure 14. Maps of Plumecoq from ANTH, FLAV, NBI_R and SFR_R indices

In 2009, chosen Multiplex indices reflected patterns in agreement with field observations. Multiplex information is complementary and different from NDVI. As GreenSeeker, Multiplex seems able to deliver annual information with FERARI index, but also to reveal past season effect with soil related indices such as FLAV, NBI or SFR. Another year of experiment will be necessary to confirm these results.

CONCLUSION AND PERSPECTIVES

For the first time, Multiplex and GreenSeeker were embedded on a caterpillar to identify variations patterns in vine vigor. Both porosity indices of each device allow to discriminate the cultivar effect on Plumecoq experimental plot. FERARI and NDVI are well correlated and allow to describe the vine vigor of the year even if Meunier had a different behaviour. However, neither indices take into account the vine vigor of previous campaigns. Other Multiplex indices like FLAV, NBI and SFR allow discriminating the three blocks as does the pruning weight or the total nitrogen content in grape juice. This result shows the interest to use the Multiplex along with the GreenSeeker. Viticultural descriptors gave some significant correlations with the sensor indices : the yield with NDVI, FERARI, SFR, ANTH and NBI; TWI with NBI_R and NBI_G and TOPO with NBI_R and NBI_G. To go further in this study, measurements will be performed in 2010 on more key stages with Multiplex and GreenSeeker. We aim to investigate more precisely the relationships between yield and sensor indices, to collect more data on the vine nitrogen status and to study the patterns stability of vine vigor variations.

REFERENCES

(1) - Agati, G., Meyer, S., Matteini, P., Cerovic, Z.G. *2007. J. Agric. Food Chem.*, 55: p. 1053-1061.

(2) - Debuisson S., Grelier M., Panigai L., Mesure de la végétation avec un capteur NDVI embarqué. 2009. Le Vigneron Champenois décembre. p. 52-71

(3) - Carbonneau, A. 1996. Une méthode simple de déterminatio/n de la surface foliaire de la vigne (Vitis vinifera L.). Prog. Agri. Vit. 113: p. 392-398.

(4) - Cartelat, A., Cerovic, Z.G., Goulas, Y., Meyer, S., Lelarge, C., Prioul, J.-L., Barbottin, A., Jeuffroy, M.-H., Gate, P., Agati, G., Moya, I., 2005. Optically assessed contents of leaf polyphenolics and chlorophyll as indicators of nitrogen deficiency in wheat (Triticum aestivum L.). Field Crops Res. 91: p. 35-49.

(5) - Cerovic, Z. G., Moise N., Agati G., Latouche G., Ben Ghozlen N., Meyer S. *2008. J. Food Comp. Anal*. 21: p. 650-654.

(6) - Dobrowski, S.Z., Ustin, S.L., Wolpert, J.A. 2003. Grapevine dormant pruning weight prediction using remotely-sensed data. Austtralian Journal of Grape and Wine Research. 9: p. 177-182.

(7) - Goutouly JP, Drissi R, Forget D, Gaudillère JP. 2006. Characterization of vine vigor by ground based NDVI measurements, VIth International Terroir Congress. p. 237-242.

(8) - Johnson, L.F. 2003. Temporal stability of an NDVI-LAI relationship in a Napa Valley vineyard. Australian Journal of Grape and Wine Research. p. 96-101.
(9) - Kolb, C.A., Pfundel, E.E. 2005. Origins of non-linear and dissimilar relationships between epidermal UV absorbance and UV absorbance of extracted phenolics in leaves of grapevine and barley. Plant, Cell and Env. 25: p. 580–590.
(10) - Kolb, C.A., Kopecky, J., Riederer, M., Pfündel, E.E., 2003. UV screening by phenolics in berries of grapevine. Functional Plant Biology. 30: p. 1177–1186.
(11) - Lamb, D., Weedon, M.M., Bramley, R.G.V. 2004. Aust. J. Grape Wine Res. 10: p. 46-54.
(12) - Mallat S. 1989.A thiry for multiresolution signal decomposition: the wavelet representation. IEEE Trans. Pattern Anal. and Mach. Intel. p. 674-693.
(13) - Profitt, A.P.B., Malcolm, A. 2005. Zonal vineyard management through airbone remote sensing. Austr. & New Zealand Grapeg. & Winem., 491: p. 40-44.
(14) - Rouse, J.W., R.H. Haas, J.A. Schell, D.W. Deering, and J.C. Harlan. 1974. Monitoring the vernal advancement and retrogradation (greenwave effect) of natural vegetation. III Final Report, Greenbelt, Md. USA.