Use of Precision Viticulture Tools to Optimize the Harvest of High Quality Grapes

Stanley Best, Lorenzo León and Marcelino Claret
Instituto de Investigaciones agropecuarias, Centro Regional de Investigación, Quilamapu, Casilla 426, Chillán, Chile.

Abstract
Under the actual conditions of international wine market, it is necessary to implement methodologies to improve the quality of the grapes to winemaking. One of them corresponds to Precision Viticulture (PV), which uses (1) ground based variables obtained from a sampling grid and (2) remote sensing tools conjunct with ground based measurement using high density determinations, like electrical conductivity properties. In Chile, few studies had been developed to incorporate the technology of PV. For this reason, the objective of the present investigation was to evaluate and compare different tools of PV (associated to 1 or at 2 type methodologies) for the visualization of associated areas to different yield and quality classes in the vineyards, in order to perform a differential harvest. For it, were evaluated the effects of the soil physical-chemical properties, leaf analysis and irrigation system over the yield and quality of grapes, by using a sampling grid of 10 points per hectare (associated to 1) or the Normalized Difference Vegetation Index" (NDVI), obtained by multispectral remote sensing, and EC with a Veris 3100 sensor (associated to 2). A low correlation was observed among the ground based variables (1) and the yield-quality of the grapes (r²<0.35). On the other hand, the NDVI shows a higher correlation for yield (r²=0.7) and quality (r²>0.76) of the grapes. On this way, it is postulated that NDVI as an integrative variable of the factors that influence the yield and quality of the vineyard. This variable will allow better vineyard monitoring, reducing costs and, at the same time, generating a clearer representation of the existent variability of the vineyards, which is a valuable tool for the crop segmentation according to qualities. Finally, it was found that a relationship of balance of 1 m²leaf/Kg-fruit shows the best results for optimize the quality of the harvested grapes.

Keywords: *Vitis vinifera* L., Precision Viticulture, Remote Sensing, NDVI, LAI, leaf/fruit ratio, grapes yield, vineyard balance map.

INTRODUCTION
In the Chilean wine industry exists a high interest in order to improve the quality of the grape to winemaking, especially considering the competitiveness in the wine market. On this respect, it is very well-known the fact that to manage the vineyards (*Vitis vinifera* L.) for producing high quality grapes, it must be managed the vigour of the plants and the balance relationships, among the leaves quantity and the fruit produced mass (Kaps and Cahoon, 1986; Kaps and Cahoon, 1992; Smart, 1985). These leaf/fruit ratios are affected by diverse factors (climate, fertility, humidity of the soil, etc) where the watering has a preponderant effect (Kliewer *et al.*, 1983; Jones *et al.*, 2002)

If we observe the case of the French winemaking industry, the vineyards are segmented according to their vigour to optimize the leaf/fruit ratios. The above mentioned, has been reached after many years of experience, demonstrating the
complexity of the delimitation of areas associated to a certain vigour or leaf/fruit ratio. This has represented a disadvantage for other countries, such as Chile where the importance of this type of information has raised only during the last years.

Among these solutions, are the vines fertility studies, soil, and irrigation, following a grid sampling methodology under the context of Precision Viticulture (PV). On this sampling method, the measurements must be developed at ground level, sampling directly on the grid specific points, with which can be generated maps by means of interpolation techniques. On the other hand, also in the context of PV, has incorporated elements of remote sensing for Leaf Area Index (LAI) determination. For this, it have been used Vegetation Indexes (VI), such as the Normalized Difference Vegetation Index, NDVI (Gitelson and Merzliak, 1997; Lamb et al., 2001) for mapping relative differences in canopy density and physiology behaviour, that can influence the yield and quality of the vineyards (Johnson, et al., 1996; 2001; Hall et al., 2002). On another hand, in different investigations the existence of a narrow relationship between NDVI and IAF has been determined (Johnson et al., 2001; 2003a,b; Lamb et al., 2001; Dobrowski et al., 2002). Moreover, with the NDVI maps, has been developed space determinations of the productivity, and also maps of balance of vineyards (leaf/fruit ratio) have been developed for the local conditions of different studies, that has been used for the differentiated harvesting of grapes for premium wines production (Johnson et al., 2001; 2003a; Hall, et al., 2002). Other applied method is the determination of soil properties with ground based EC sensors, which gives high density information of soil variability map. However, the vine balance, the nutritional standards, CE standards and the relationships NDVI & IAF are not applicable among areas with different handling and agroclimatic conditions, since the interaction between the electromagnetic radiation and the terrestrial vegetation is complex, with numerous variables that affect the form and intensity of the reflectivity and/or absorption, affecting the remote sensing determinations (Tucker et al., 1981; Gitelson and Merzliak, 1997), which depends on diverse factors (Huete and Jackson, 1988; Yoder and Pettigrew-Crosby, 1995; Gitelson and Merzliak, 1997).

In Chile do not exists precedents in the use of technologies associated to PV. This means that for the Chilean conditions, there are not comparisons in order to establish the specific PV methodology to be used (associated to grid point sampling or remote sensing and high density soil sampling methods). On the other hand, one of the biggest necessities in the industry is linked to the yield forecast and the standards in order to obtain an optimal leaf/fruit ratio range to improve grape quality. The present investigation had as objective the evaluation of different methodologies linked to the PV, for the definition of management/harvest areas, yield prediction, and the definition of standard leaf/fruit ratio range in the production of high quality grape and determine its applicability under the Chilean productive conditions.

**MATERIALS AND METHODS**

This study was carried out during the 2002/03 season, on a 9 years old vineyard var. Cabernet Sauvignon over a 2.2 ha area. The vineyard is planted with a 0.5m x 2.8 m spacing, is managed with a simple espalier training system and is located on (735.401 E; 6.013.154 N, H18 WGS84), Cauquenes, Chile. The climate corresponds to a Mediterranean type. The irrigation system corresponded to drip. The pruning considered a density of 20 buds/m.

For the spatial determination of the soil and crop properties, measures in ground basis, were developed in a systematic non – aligned grid inside the work area, with a
density of 10 samples/ha, considering a total of 22 sampling points (SP) (fig.1). Each SP on it grid was positioned by means of a DGPS system. Soil samples were taken in each SP, on the plantation vine line, on 3 depths (0-30, 30-60 and 60-90 cm), during full bloom for the physical properties (percentage of sand, loam and clay, field capacity and the permanent wilting point), and chemical determination, (pH, Organic Matter, N, P, K, Ca, Mg, Na, Al, Zn, Fe, Cu, Mn, B and S). On the other hand, to determine the nutritional state in the 22 SP, a representative leaf sample from 5 plants on each SP was taken, for determining the same properties taken from the soil samples. In the same 5 plants/SP the production of the vineyard was evaluated, extracting and weighting all bunches of each plant during the commercial harvest. Also, for each SP, from different fruit sub samples, the soluble solids, total acidity, pH, and the Antocianins and Phenolic content were determined as quality variables in the grapes. Lastly, the irrigation uniformity was determined by obtaining the respective variability coefficient of the irrigation rates.

To identify the possible outliers on the ground information before mentioned, a spatial cartograms map was used based on a non-linear cellular automata algorithm implemented in the GeoDa ver 0.9.5i5 software package (Anselin, 2005), reducing only 3 SP.

An airborne mounted multispectral Camera (DuncanTech, MS3100) was used for obtaining the vineyard images, in a digital three bands format, corresponding the band nº 1 to the green, (540 nm in the centre of the band, with a band width (BW) of 40 nm), the nº 2 to the red one (660 nm, 40 nm BW) and the nº 3 to the Near Infrared (800 nm, 65 nm BW). The flight altitude was 2850 m and the images were obtained with a horizontal covering of 1000 m and a resolution of image of 2 m/pixel. Starting from the captured images, the NDVI of the vineyard was determined, using the equation (1).

\[
\text{NDVI} = \frac{\text{band 3} - \text{band 2}}{\text{band 3} + \text{band 2}}
\]  

Where, the bands 3, 2 and 1, they correspond to the radiometric values obtained for each pixel on the image bands, with this an image of the vineyard NDVI was determined, using the ERDAS v.8.5 software. The NDVI was subdivided in 3 classes of vigour, (Fig. 1), using a Cluster Analysis for the correct variable graphic representation. The NDVI maps was used to define specific sampling points to obtain a ground basis directly (LAI) measurements on order to correlate this values with the NDVI. For this, 3 representative points on each class of vigour were selected, in which all the leaves of two plants were picked up, measuring its total area by means of an (AM200 Portable Area Meter) instrument. The CE determinations were performed using a Veris 3100 Soil EC Mapping System, with a 6 by 5 m sampling data.

To obtain the yield maps and yield equations, an estimation of spatial lag models (spatial regression), supported by Maximum Likelihood method (Anselin and Bera, 1998), was performed, based on the bunches counting and weighting ground data, associated with the spatial neighbourhood obtained from the NDVI maps.

Also, were determined the leaf/fruit balance areas, considering the plant yields, and the interpolation maps of the yield information, using the adjustment curve before mentioned. On the other hand, by a spatial regression analysis were associated the values of NDVI to the grapes yield - quality and soil EC information, considering the vicinity and spatiality of the variables based on the NDVI maps. A Factor Analysis was used to determine the variable or group of variables that better explain the variabilty of yield and grapes chemical characteristic. The Moran i index (Moran, 1950) was used to determine
the degree of spatial correlation that present each variable in the study. For the spatial analysis, GeoDa ver 0.9.5i5 software package routines were utilized (Anselin, 2005).

RESULTS AND DISCUSSION

As a result of the irrigation uniformity test, a good performance was found, with a 85% of uniformity, in that way the irrigation system did not put noise in the vineyard variability.

The variables measured on a ground basis using the grid method, showed a not strong correlations ($r^2<0.4$) with the grapes yield and quality, when the spatial relationships was not included and just regular or multifactor regression was used. The above-mentioned would be due to the density of SP for the vineyard characterization was not enough, even when they were determined at a density of 10 SP/ha, then, it is not very practical to employ a regular grid sampling for the variables measures on ground basis because it is very difficult to define the real amount of sampling of some area without know their variability, thus, it is necessary to have some other tools to define the spatial variability and continuity of the vineyards. Such information should be the NDVI or EC maps as we used in this research and we explain as follow.

The values of NDVI (fig. 1) associated to yield and quality information of grapes, presented high spatial correlation levels ($r^2>0.7$; Total Acidity ($r^2=0.6$). These correlations increased at included EC information on the generated multifactor spatial regression models. With this information, a yield vineyard map was generated (fig 2). On another hand, a high correlation exists among the leaf area (m$^2$ leaf/m soil) and the values of NDVI, ($r^2$ of 0.75). This high correlation level, allowed modelling the leaf volume of the whole study area. The Fig. 3 shows the balance map among leaf area and yield derived from the leaf area and yield maps.

From the fig. 3, can be deduced that in the areas with high m$^2$leaf/Kg-fruit. (> 1.3) relationship, fruit presents low sugar concentration (<24º Brix), on the other hand, the areas with low m$^2$leaf/Kg-fruit (<0.7) relationship possess high sugar levels (>25º Brix). Finally, in areas with an intermediate balance (0.7-1.3 m$^2$leaf/Kg-fruit), a good sugar concentration is reached (24-25º Brix). On another hand, a high correlation was observed among grape quality variables, vigour level and the leaf/fruit ratio, where colour factors (Antocians) and the aromatic factors (Phenols) were inversely proportional to the leaf/fruit ratio (Fig. 4). These results indicate that exist a relationship between the leaf/fruit ratio and grapes quality chemical characteristics, with a clear tendency in a reduction of its with a higher leaf/fruit ratio (or increasing in vigour).

Finally, the NDVI derived from multispectral images is presented as a variable with an integrative and robust character for the segmentation of yields and quality areas due to physiologic importance of the LAI in the vine, in the expression of the local vigour, which is related with the spatial variability of the vineyard, factor that must not be forgotten for a correct analysis. This result is also related to the density of NDVI and EC information. The above-mentioned allows developing a sampling directed with a resulting reduction in vineyard sampling costs. With a directed monitoring, optimal balances (leaf/fruit ratio) in the vineyards can be obtained with more precision, which permits quality handling by means of modifying this ratio with agronomic manage (vineyard pruning, crop load, irrigation, etc). Also, this information is of great utility for the differentiated harvest of grapes for the premium production wines, with the possibility to demarcate in a map the areas with bigger or smaller grapes quality potential for the winemaking. This methodology presents the advantage of constituting a quick application
tool with relatively low cost for the conditions of the Chilean viticulture. However, these studies should be validated on a temporary base. On this way, more investigation is required in order to study the variation of these factors among seasons.

CONCLUSIONS

The NDVI, it is presented like a highly useful variable for the yield and quality estimation in the vineyards under our study conditions. On the other hand, a very important complement to the NDVI information is the EC values determined on a ground basis, but with high density sampling base. On this way, The NDVI presents the advantages of being an integrative and robust variable of the physiology of the plant, easily transferable to the Chilean viticulture sector. On the contrary, the ground basis measured variables using a grid sampling method presented low correlations with the yield variables, even considering 10 SP/ha. In that way this methodology is less transferable and expensive. Finally, under the study conditions, it was really important to include the information spatiality and continuity in the analyse, in order to get a correct interpretation of the data.

Acknowledgments

This investigation was integrated under the activities of the project “Desarrollo de la tecnología de manejo sitio específico en viñedos, para mejorar la calidad de la uva a vinificar” supported by the Fundación para la Innovación Agraria (FIA). Special thanks to Martínez de Salinas Vineyards.

Cited literature


---

**Figure 1.** NDVI map and sampling point for the study area.
Figure 2. Interpolated Study area yield map.

Figure 3. Study area equilibrium map.
** 1=Low Vigour, 2=Medium Vigour and 3=High Vigour.

**Figure 4.** Average Grapes chemical quality factors by level of vigor in study area.
Utilisation de la viticulture de précision pour optimiser la vendange de haute qualité

Mots clés : viticulture de précision, télédétection, NDVI, LAI, rapport fruit sur surface foliaire, rendement, cartographie.

Résumé

La compétition du marché du vin au niveau international impose le développement de nouvelles méthodes pour améliorer la qualité des vins. La viticulture de précision (VP) constitue l’une de ces méthodes, elle utilise (1) des paramètres mesurés in situ selon un maillage régulier et (2) la télédétection en association avec des données à haute résolution comme les propriétés électriques des sols. Au Chili, peu de travaux ont fait état de l’utilisation de la PV. L’objectif de ce travail est d’évaluer et de comparer différents outils de la VP (en association avec les méthodes de type (1) ou (2) pour la mise en évidence de zones présentant des rendements et des qualités différentes. L’objectif étant de mettre en œuvre une vendange sélective sur certaines zones. A cette fin, l’effet des propriétés physico-chimiques du sol, l’analyse des feuilles et de l’irrigation sur le rendement et sur la qualité des fruits ont été évalués avec un maillage de 10 points par ha. (pour méthode 1) ou la « Normalized Difference Vegetation Index » (NDVI), obtenu par image multi-spectrale et l’EC avec un capteur Veris 3100 (associé à 2). Une faible corrélation a été observée entre les variables mesurées in situ (1) et le rendement-qualité des fruits ($r^2<0,35$). En revanche, le NDVI a montré une forte corrélation avec le rendement ($r^2=0,7$) et la qualité ($r^2>0,76$) des fruits. Ainsi, nous supposons que le NDVI est un paramètre « intégratif » des facteurs qui affectent le rendement et la qualité du vignoble. Cette variable permettra ainsi une meilleure gestion du vignoble, réduisant les coûts et par la même occasion, elle donnera une représentation claire de la variabilité qui existe au sein du vignoble, ce qui constitue un outil intéressant pour sélectionner la vendange en fonction de la qualité. Enfin, il a été montré qu’un équilibre de 1kg de fruit/m² de feuillage était le meilleur compromis pour optimiser la qualité des fruits.