Monitoring water deficit in vineyards by means of Red and Infrared measurements

Suivi du déficit hydrique dans les vignobles à l'aide de mesures dans le rouge et infrarouge

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Abstract: Vineyard water availability is one of the most important variables both in plant's production and wine quality, once it regulates several processes, among which the stomata activity. To avoid water deficit, wine producers introduced artificial irrigation in their vineyard, using a semi-empirical process to calculate water amount. Some previous research presented measurements in the infrared wave bands and PAR (photosynthetic active radiation) as a process to estimate water stress and to calculate water needs. This paper analyses and explores the relationship that could be established between red, infrared and PAR in vegetation indices calculation and leaf area index and the relationship between these indices and water availability or deficit. Data from this process could be used to design irrigation schemes, saving water and controlling vineyards needs.

Key words: vineyards, water deficit, red and infrared, vegetation Index (NDVI)

Introduction

The Douro Demarcated Region, with 45,000 hectares of vineyard area, is divided in three sub-regions, each with different climatic conditions with different limitations to photosynthesis (Moutinho-Pereira *et al.*, 2004), and constrains to quality under sever water limitations (Oliveira *et al.*, 2003).
The adoption of new systems for establishing vines, in single or two furrow terraces, or in slope vineyards, sometimes causes differences in growth development, whether through differing soil and climate conditions between the inner and outer furrow, in the case of terraces (Oliveira, 1993), or in the different levels of the slope vineyard sections (Moutinho-Pereira *et al*., 2001), namely with regard to the availability of water for cultivation (Oliveira, 2001).
Predawn water potential is considered by various authors to be a powerful tool for assessing plant water status (Lopes *et al.*, 1998; Deloire *et al.*, 2005). Recently, there have also been studies in the use of stem water potential, for early detection of water stress (Choné *et al.*, 2001).
Meanwhile a new possibility has arisen involving the application of vegetation indices (Rouse *et al.*, 1973), among them the NDVI (Normalised Difference Vegetation Index), which is based on the significant reflection differences displayed by vegetation in red and near infrared frequencies, according to the following equation, *NDVI = (Infrared-Red)/(Infrared+Red)*, where near infrared and red are, respectively, the reflections of each of the frequencies (Rouse *et al.*, 1973). NDVI is a number between -1 and +1, where negative values are associated with the presence of liquid water and positive values with the presence of vegetation. For plants with dense vegetation, the NDVI will be close to 1, while for plans with little vegetation, the NDVI will be close to 0. However, negative values are rare in natural subjects (Rouse *et al.*, 1973). Among other, advantages of these indices results from the near infrared reflection being from the inside surface of the leaves, which allows for indirect knowledge of the physiological status of the leaf.
As leaves represent the main surfaces of plant canopies where energy and gases are exchanged, their optical properties are essential to understanding the transport of photons within vegetation. Because of the importance of photosynthetic function, leaf optical properties have been the subject of hundreds of studies since the middle of the last century.
The aim of this paper is to analyse and explore the relationship that could be established between grapevine water status in step slope vineyards in different topographic localisations evaluated by grapevine water

potential indicators. Always examine the use of red, infrared and NDVI measurements in vegetation to monitoring water stress.

Materials and methods

The experiment was carried out in 2004, in a section of commercial vineyard situated in the Quinta dos Aciprestes, Foz do Tua, with a semi-arid, mesothermal Mediterranean-type climate, with average annual rainfall of 560 mm (INMG, 1965).

The vineyard was planted in 1998 in schist complex soil, with a depth of 1.2 m. Vines of the Touriga Nacional variety were grafted on 196-17 rootstocks, planted at distances of 2.0 m x 1.1 m, in a slope vineyard landscape systematisation, with the slope of the section being 25%. The vines are grown and trained on bilateral *Royat*, with upward growth and average pruning of 12 buds per plant.

Two modalities were considered for this experiment, unirrigated vines, 0% ETc (**NI**) and vines with a watering regime of 60% of ETC (**I**), calculated according to the method proposed by Penman-Monteith as described in Allen *et al.*, (1998), using a weather station set up in the section. Irrigation was by drip irrigation, once a week between 25 June and 30 August. These modalities were split in tow levels of the slope, **b** (down) and **c** (top).

The predawn (Ψ_{pd}), midday (Ψ_{l}) and stem water potential (Ψ_{s}) was measured on six dates, between June and the third week of September. The readings were made using adult leaves in six consecutive vines of each modality, with a pressure chamber, model ARIMAD, ELE International, with a precision of 0,01 MPa, according to Scholander *et al.* (1965).

The pre-dawn water potential (Ψ_{pb}) was measured at the end of the night in uncovered leaves, the mid-day water potential (Ψ_{l}) was measured at midday in adult leaves that had been directly exposed to sunlight for at least two hours before the reading. The stem water potential (Ψ_{ps}) was measured in non-transpiring leaves, which had been previously bagged in black plastic and wrapped in aluminium foil for at least one hour before the reading, so as to avoid overheating. The purpose of bagging is to prevent leaf transpiration, thereby equating leaf water potential with stem water potential (Choné *et al.*, 2001). Leaves from the shady side of the row were selected for bagging, to avoid heating of the leaves.

Additional, for each blocks, leaf gas exchanges measurements were performed using a portable gas exchange system (LCA-3, Analytical Development Co., Hodesdon, England), the production parameters were determined at harvest. At the winter pruning, pruning weight per vine was determined. The results were submitted to statistical analysis through studying the ANOVA and correlation test.

The reflection of red (R) and near infrared (IR) radiation was measured with a spectroradiometer SKR110 with 660/730 sensor (Sky Instruments. Lda, England), between 12 p.m. and 3 p.m. local time, under clear skies and in the part of the vineyard directly exposed to the sun, four times in five adjacent vines.

The photos for infrared measurements were taken with a Nikon F-501 camera, using Kodak film infrared sensitive (Ektachrome Infrared EIR), at a distance of 570 meters (panoramic, with 75-300 mm lens) and 2 meters (local, with 35-80 mm lens), both lens with a yellow filter K2 (Hoya, Japan).

Results and discussion

It was a very hot and dry year. Between November 2003 and September 2004, rainfall was only 300.4 mm, around 54% of that in a normal year. It should be noted that following a phase of dry growing conditions, there was a period of 61 mm rainfall, mainly in the second and third week of August (figure 1).

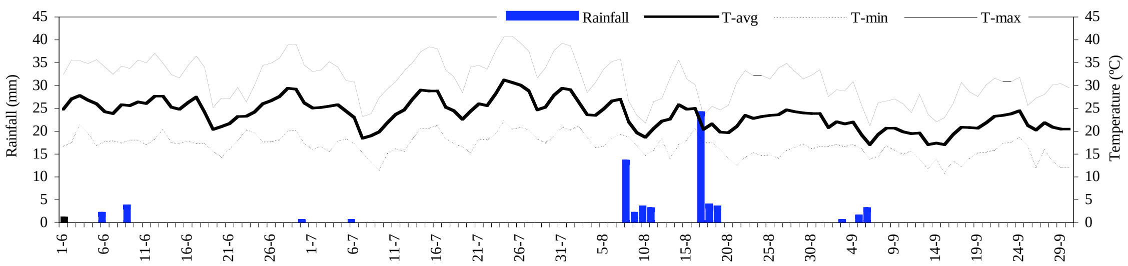

Figure 1 - Rainfall (bars), mean, maximum and minimum temperature (lines) during the study (June-Sep2004).

As expected, as the dry season progressed, there was a progressive reduction in pre-dawn water potential (figure 2), until the reversal occasioned by the August rains. This pattern was not as obvious with regard to stem water potential mid-day water potential (data not show).
On the other hand, from the second date, the predawn water potential showed differences between the two irrigation regimes, with the un-irrigated vines registering lower values and also with differences registered between the higher and lower levels of the irrigated vines. This situation became more marked on the third date, where this value clearly separated the two land levels with the drop in soil water content. At this date, the predawn water potential in I-c achieve values (-1.2 MPa). According (Shultz and Matthews, 1998), these values are mainly associated with cavitations of the xylem shoot apex that could restrain vegetative growth. Following the water recovery on the fourth date, a development in the same pattern of variation could be observed.

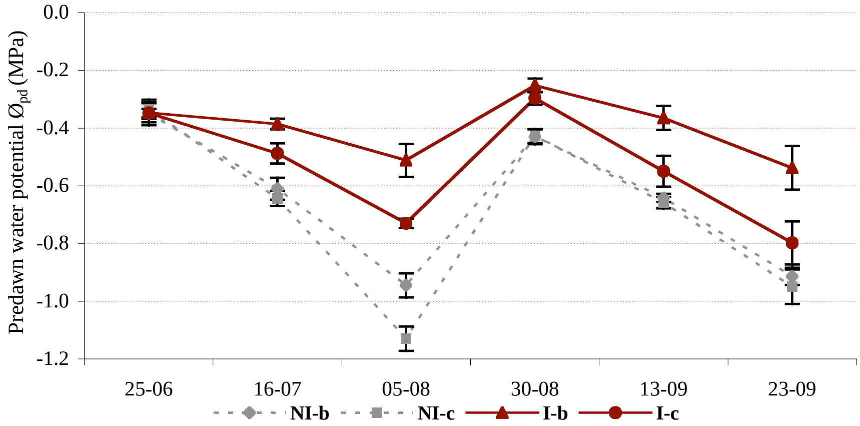

Figure 2 - Seasonal Ψ_{pd}, on the four plots (NI-0% Etc, I-60% Etc, b-down, c-top.
Data are means of six measurements on six adjacent vines. Error bars indicate s.e.

Stem water potential and minimum leaf potential were also performed in this study in previous work (Alves *et al*., 2006), but did not register the same discriminatory capacity as predawn water potential, possibly due to the luxury consumption by the plant and the strong effect of stomata regulation that normally occur in the Douro Region vineyards, according to Moutinho-Pereira *et al.* (2004).
Diurnal photosynthetic rate (*Pn*) and stomatal conductance (*gs*) showed similar behaviour to those found in predawn leaf water potential among treatments, to the day 05-08 (figure 3). In fact, values of *Pn* and *gs* of irrigated plants were significantly higher than none irrigated plants, mainly in down locations (b), of the experimental trial.
The net photosynthesis showed to be highly correlated (in 05/08) with the predawn water potential (figure 4).

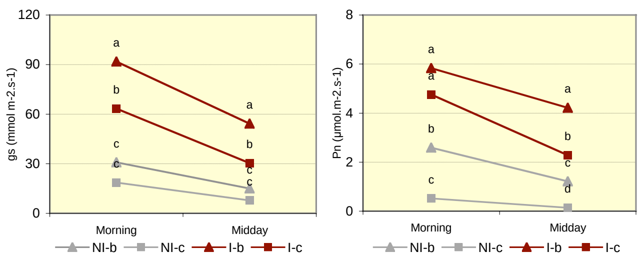

Figure 3 - Diurnal changes in net CO_2 assimilation rate (*P*N) and stomatal conductance (*gs*) in 05-08.
Different letter suffixes show statiscally differences at P<0.05

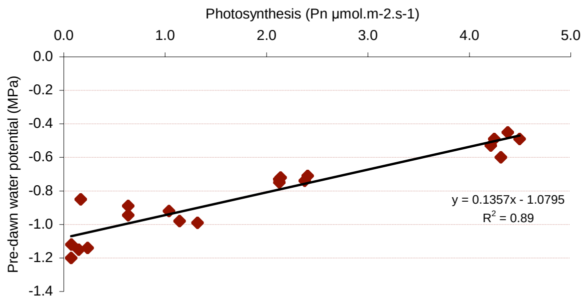

Figure 4 - Relationship between photosynthesis (Pn) and Ψ_{pd} in 05-08

In relation to the production patterns (table 1), it must be underlined that, in spite of the absence of variation of plant yield between levels (only between irrigation treatments), the pruning weight was inferior both in 0% ETc and in lower levels.

Table 1 - Yield and vigour components under treatments (n=8)
Different letter suffixes show staticsally differences at $P<0.05$

	Yield (kg per vine)		Pruning buds (per vine)	Pruning weight (kg per vine)		Shoot number (per vine)	Cluster number (per vine)	
NI-b	1.55	b	11.00	0.76	a	15.35	16.60	b
NI-c	1.54	b	11.63	0.57	a	14.05	19.60	ab
I-b	3.71	a	10.88	0.90	ab	14.55	21.80	ab
I-c	3.36	a	10.63	0.95	b	14.35	24.80	a

With regard to the NDVI values calculated (figure 5), there was a trend in variation similar to that mentioned for the water potentials, demonstrating possibilities for discriminating between distinct watering regime systems, namely during periods of greater grapevine water stress. On the other hand, this being an indicator that reflects the internal status of the leaf, there was a tendency for greater inertia on the variation following the August water distribution, which, although very important, occurred during a phase of evident degradation of the vegetation.
The relationship achieved between NDVI and predawn leaf water potential (figure 6), allows us to developed further work with the aim to optimise this methodology, and validate this relationship with a more accurate hyper spectral sensor, for others cultivars and different environmental conditions.

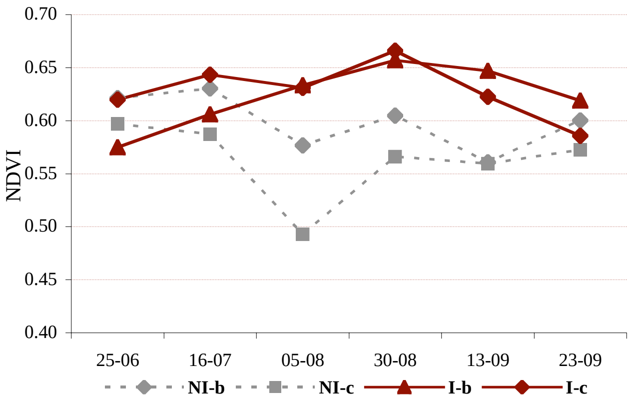

Figure 5 - Seasonal NDVI, on the four plots
(NI-0% Etc, I-60% Etc; b-down, c-top). n=4

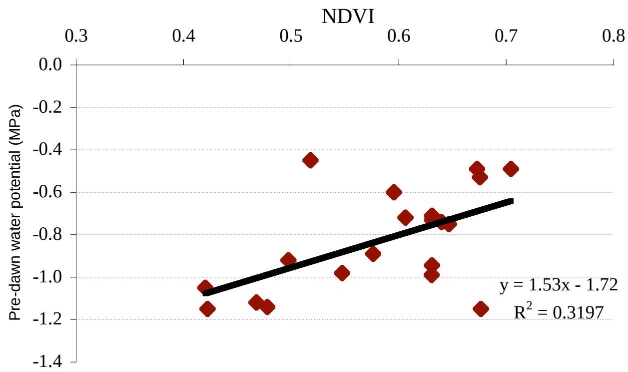

Figure 6 - Relationship between NDVI and Ψ_{pd} in 05-08.

On the other hand, the NDVI depends directly on the reflection of near infrared and a relation may be established between this and the chromatic intensity registered in infrared sensitive skins as shown in figure 7.
In these images, the irrigated zone displays greater depth of row of vegetation, whether through direct observation (figure 7A), or indirectly (figure 7B), after image processing and cluster classification (Reis, 2001) using IDRISI 32 software (Eastman, 2001).
In the local photographs (figure 8), this same relation is made evident by the increase within shadow in the row of vegetation. Future work will be needed to establish a mathematical relation between the radiometric intensity and the field measurements.
With the possibility of new digital cameras that can register photographs in separate strips (8 bit number matrix), it will be possible to link the values measured in the field (water potentials, radiation, etc.), with the registration of those images, and process the values using multidimensional analysis methods, as is done with satellite images.
Although, predawn water potential seams a sensitive indicator to the severe drought conditions in Douro, they present a limitation to the quantity of the determinations that are able to perform on a single day. The use of these new methodologies will allow us for map zoning by shading, which will be more expeditious and trustworthy since it is based on internal plant parameters, allowing the vine producer to define the technical itineraries for managing the vineyard.

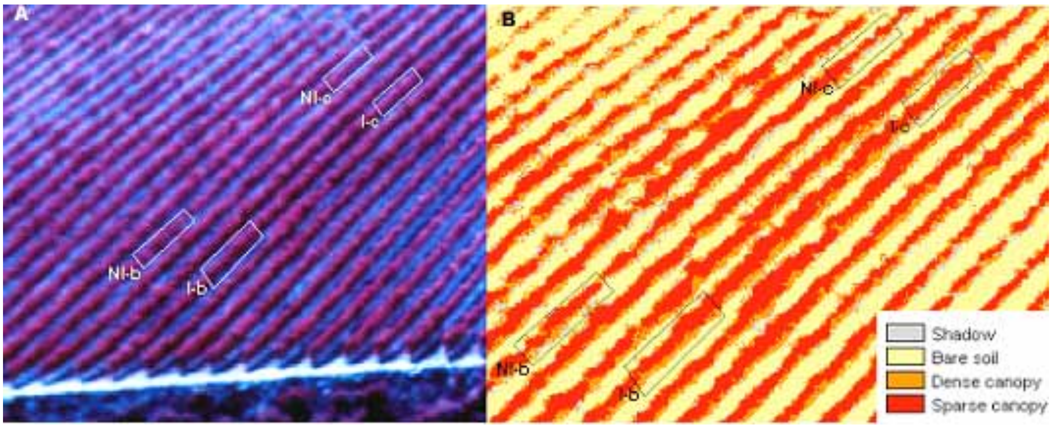

Figure 7 - Panoramic photos in false colour* (A), and afterwards image processing with IDRISI 32 (B).
* Photos made with infrared sensitive film (radiation not visible to the human eye), afterwards coloured in order that the infrared is represented in red/violet.

A

B

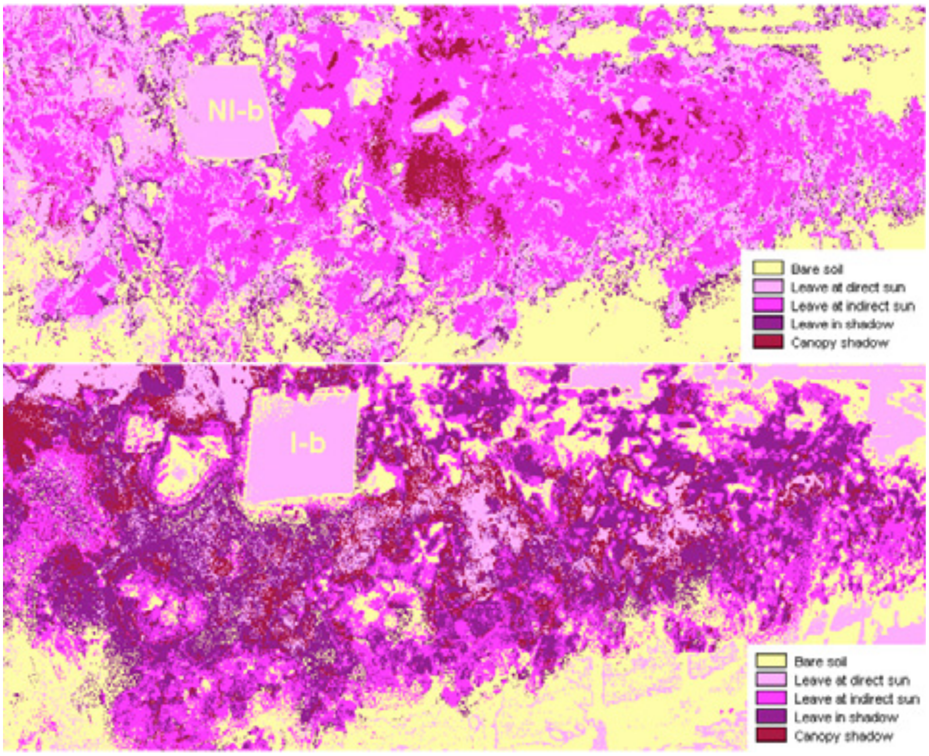

Figure 8 - Local photos at false colour afterwards image processing with IDRISI 32.
(A) 0% ETc (NI-b), (B) 60% ETc (I-b).

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