Assessing plant water relations based on hidden information in the hyper-spectral signatures: Parameterization of olive leaf P-V curve and estimation of water potential components

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Introduction and Objectives

Soil-Plant-Atmosphere Continuum (SPAC) is characterized by complex structures and biophysical processes acting over a wide range of temporal and spatial scales. Moreover, in olive groves, the plant adaptive strategies to respond to soil water-limited conditions make these systems even more complex. One of the greatest challenges in hydrological research is to quantify changes in plant water relations. A new promising technology is represented by field spectroscopy. New detectors, characterized by very high resolution and operating over a spectral range variable between 300 and 2500 nm, allow detecting narrow reflectance or absorbance peaks, separating close lying peaks and discovering new information, hidden at lower resolutions.

The general objective of the research was to investigate on the pressure-volume (P-V) curve of olive trees in a non-destructive and repeatable way, as well as to propose methodologies aimed to parameterize the different compartments characterizing the SPAC system (soil or plant). Hyper-spectral data were used to characterize the hydraulic P-V curve of olive leaves, as well as to estimate, indirectly, the two main components of leaf water potential, i.e. turgor and osmotic potentials.

Material and Methods

Experiments were carried out in an olive grove of Western Sicily, during the mature phase of the first vegetative flush. Leaf spectral signatures and associated P-V measurements were acquired on olive leaves collected from well-irrigated plants, as well as from plants maintained under moderate or severe water stress.

Leaf spectral reflectance was monitored with a FieldSpec 4 spectro-radiometer (Analytical Spectral Device, Inc.), in a range of wavelengths from VIS to SWIR (350-2500 nm), with sampling intervals of 1.4 nm and 2.0 nm, in the regions from 350 to 1000 nm and from 1000 to 2500 nm respectively. Measurements required the use of contact probe and leaf clip (Analytical Spectral Device, Inc.) specifically designed for plant leaves. Figs. 2 and 3 show the phases of leaf spectral reflectance signatures and leaf water potentials measurements. To obtain a suitable signal to noise ratio, a number of 10 scans per spectrum were acquired.

Fig. 1 - Experimental setup used for the research activity and technical features of FieldSpec 4 Standard-Res Spectro-radiometer with annex plant probe (downloaded from www.asdi.com)

Spectral Range	350-2500 nm
Spectral Resolution	3 nm @ 700 nm; 10 nm @ 1400/2100 nm
Sampling Interval	1.4 nm @ 350-1050 nm; 2 nm @ 1000-2500 nm
Scanning Time	100 milliseconds
Stray light specification	VNIR: 0.02%, SWIR 1 & 2: 0.01%
Wavelength reproducibility	0.1 nm
Wavelength accuracy	0.5 nm
Maximum radiance	VNIR 2X Solar; SWIR 10X Solar
Channels	2151
Detectors	VNIR detector (350-1000 nm): 512 element silicon array SWIR 1 detector (1000-1800 nm): Graded Index InGaAs Photodiode, TE Cooled SWIR 2 detector (1800-2500 nm): Graded Index InGaAs Photodiode, TE Cooled
Input	1.5 m fiber optic (25° field of view). Optional narrower field of view fiber optics available.
Noise Equivalent Radiance (NEdL)	VNIR: 1.0 X10-9 W/cm2/nm/sr @ 700 nm SWIR 1: 1.2 X10-9 W/cm2/nm/sr @ 1400 nm SWIR 2: 1.9 X10-9 W/cm2/nm/sr @ 2100 nm
Weight	5.44 kg (12 lbs)

Length	10" (25.4 cm)
Weight	1.5 lbs (.7 kg)
Power requirements	12-18 VDC, 6.5 W
Light source type/Life	Halogen bulb/1500 hours
Halogen bulb color Temp.	2901 +/- 10º% K
Spot size	10 mm

Fig. 2 – Measurements of Leaf spectral reflectance

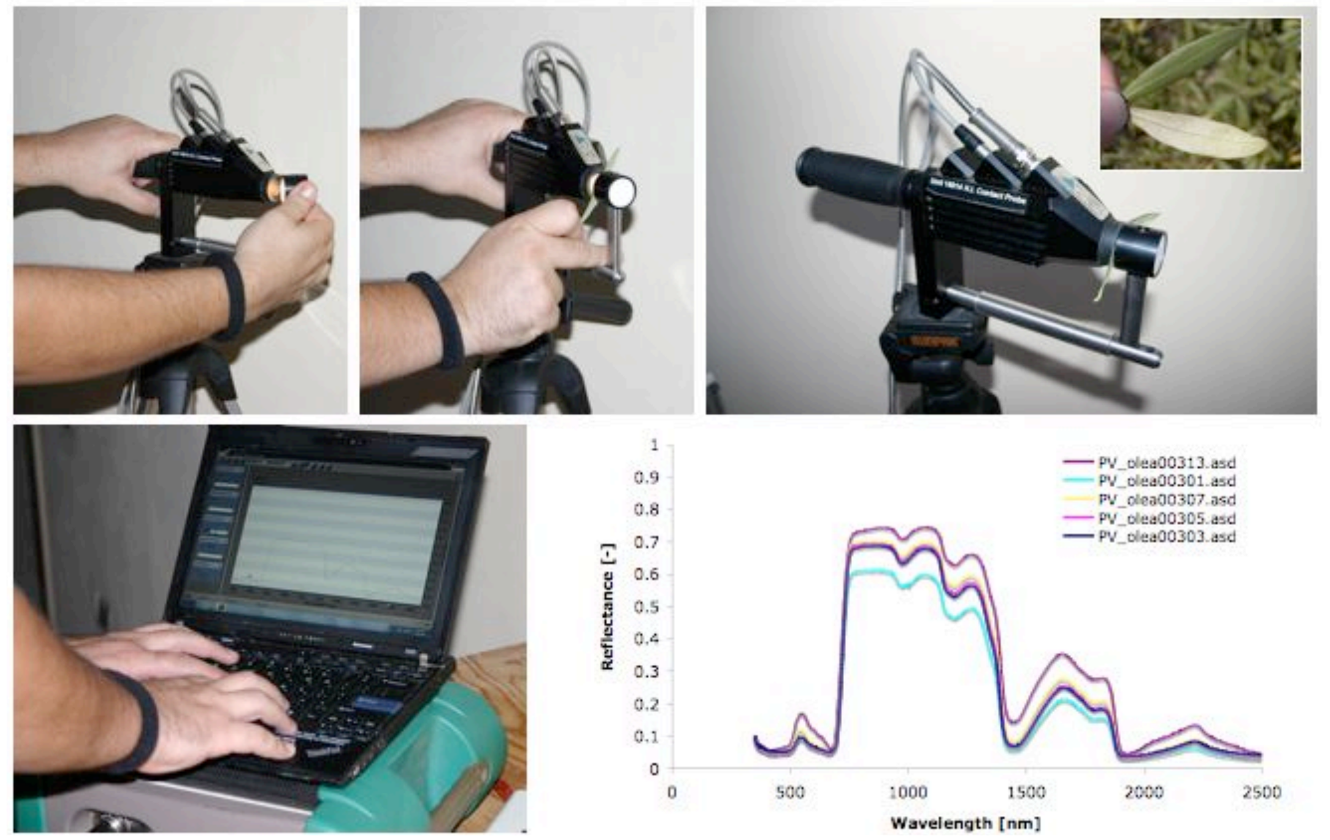


Fig. 3 – Measurements of Leaf water potential

Immediately after each spectral acquisition, leaf potential, LWP and its relative water content, RWC, were measured by following the standard procedure adopted to detect leaf P-V curves (Vilagrosa et al., 2003). LWPs were measured with a Scholander pressure chamber (Skye, Powys, UK) and a stereomicroscope (40x magnification), allowing to improve the quality of determinations. The relationship between LWP components and relative water content (RWC) was represented by means of the Höfler diagram (Richter, 1978).

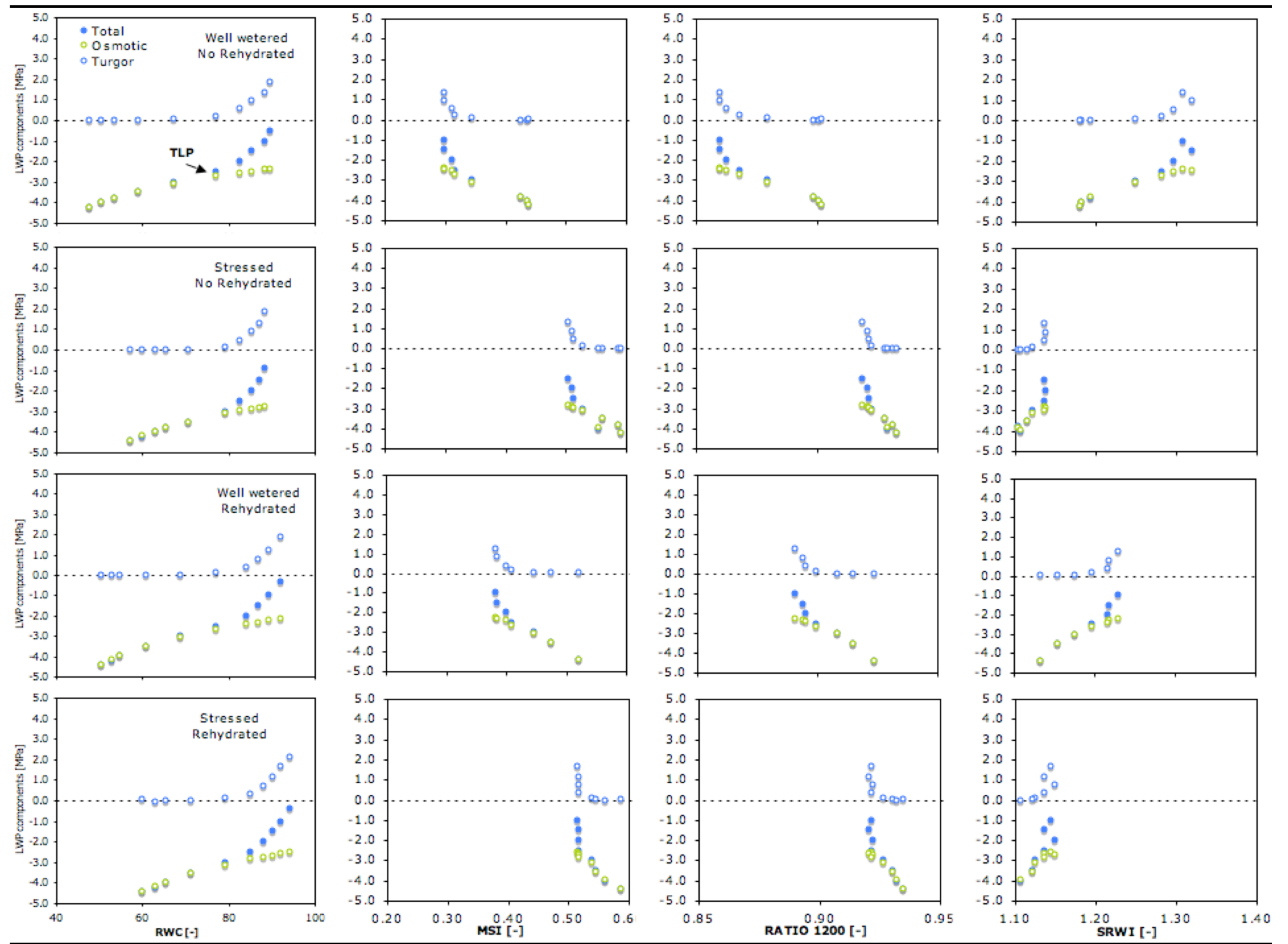
Results and Discussion

In order to characterize the P-V curve and to estimate the LWP components, spectral indices were examined by considering the water absorption features in both SWIR domain, sensitive to changes in leaf water content, and NIR domain, sensitive to changes in leaf internal structure. A number of spectral indices were identified to describe the patterns of Höfler diagram associated to leaves collected on trees maintained at different levels of water stress.

Left column of Fig. 4 shows the Höfler diagram in which LWP, as well as its turgor and osmotic components are represented as a function of the relative water content (RWC). The rows illustrate the Höfler diagram obtained on four leaves, two of which collected in well watered trees and the other two on stressed trees, without and with rehydratation. On the other three columns of fig. 4, the same LWP components are plotted vs specific spectral reflectance indices, obtained by using ratios or differences between reflectance values at given wavelengths. The values of considered indices were determined based on the relationships indicated in the lower part of fig. 4. The choice of such indices depends on the characteristics of water absorption in SWIR and NIR domains of the spectrum.

A first qualitative analysis of fig.4 shows how the considered indices reflect, in a certain way, the patterns identifiable on the Höfler diagram. Moreover, it has to be noticed that the different indices allow to identify characteristics points of the Höfler diagram, like those related to the turgor loss (TLP).

Fig. 4 – Höfler diagrams and preliminary relationships between the components of leaf water potential with spectral indices. TLP=Turgor Loss Point



$$RWC\,[\%] = \frac{W - DW}{TW - DW}100$$

(Barr and Weatherley, 1962)

$$MSI = \frac{\rho_{SWIR}}{\rho_{NIR}}$$

(Hunt et al., 1989)

$$RATIO_{1200} = \frac{2\rho_{1180-1220}}{\rho_{1090-1110} + \rho_{1265-1285}}$$

(Gao and Goetz, 1994)

$$SWRI = \frac{\rho_{NIR}}{\rho_{SWIR}}$$

(Gao and Goetz, 1996)

Future developments

Research will be addressed to parameterize leaf P-V curve, based on information extracted from high resolution hyper-spectral features, where cell wall/energy, water/energy and cell wall-water/energy interaction occur. Specifically, the following P-V curve parameters will be identified:

- RWC associated to bound water in the cell walls, evaluated at the intersection between P-V curve and x-axis;
- Inverse of osmotic pressure at turgor-loss point and the corresponding RWC;
- bulk elastic module, identified as slope of the linear relationship between imposed water stress and the corresponding strain value, in the range of RWC from saturation to the turgor-loss point.

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