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in

Santini A. (ed.), Lamaddalena N. (ed.), Severino G. (ed.), Palladino M. (ed.).
Irrigation in Mediterranean agriculture: challenges and innovation for the next decades

Bari : CIHEAM
Options Méditerranéennes : Série A. Séminaires Méditerranéens; n. 84

2008
pages 69-75

Article available on line / Article disponible en ligne à l'adresse :

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To cite this article / Pour citer cet article

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Crop water status estimated by remote sensing information

A. D. Palumbo, P. Campi, F. Modugno, M. Mastrorilli

Agricultural Research Council - Research Unit for Cropping Systems in Dry Environments (CRA - SCA)
Bari, Italy

Abstract. Techniques to more accurately quantify crop water status are needed for determining crop water requirements and appropriate irrigation scheduling. Remote sensing techniques are a possible tool for estimating the crop water status. To verify this hypothesis, in 2007 a measurement campaign was carried out in Rutigliano (lat. 41°01' N, long. 17°01 E, alt. 147m a.s.l.), with the tomato as the test crop. This crop was subjected to three irrigation treatments. To monitor the water status, both 'remote sensing' (NDVI and radiative surface temperature) and 'manual' measurements (stomatal conductance and pre-dawn leaf water potential (PLWP)) were used. The NDVI index is a function of both crop growth (LAI and biomass) and the crop water status. The experimental data showed a linear relationship between PLWP and NDVI. From this relationship it seems possible to predict the crop water status starting from completely automatic measurements. Although additional research is needed, the remote sensing technique potentially offers an improvement of the irrigation scheduling.

Keywords. NDVI – Radiative temperature – Stomatal conductance – Pre-dawn leaf potential (PLWP).

Estimation de l'état hydrique des plantes par télédétection

Résumé. *Des techniques capables de quantifier d'une manière précise l'état hydrique des plantes cultivées sont nécessaires, afin de déterminer les besoins en eau des plantes ainsi que le programme à adapter pour le pilotage de l'irrigation. La télédétection est un instrument possible pour évaluer l'état hydrique des plantes. Pour vérifier cette hypothèse, une campagne de mesures a été menée en 2007 à Rutigliano (lat. 41°01' N, long. 17°01 E, alt. 147m), sur une culture de tomates. La parcelle cultivée a été soumise à trois traitements d'irrigation. Afin de suivre de près l'état hydrique de la plante, la télédétection (NDVI et température de surface radiative) ainsi que les mesures "manuelles" (conductance stomatique et potentiel hydrique foliaire de base PLWP) ont été utilisées. L'indice NDVI est une fonction de la croissance (LAI et biomasse) ainsi que de l'état hydrique des plantes. Les données expérimentales ont montré une relation linéaire entre PLWP et NDVI. De cette relation, il semble possible de prévoir l'état hydrique des cultures à partir de mesures complètement automatiques. Bien qu'une recherche supplémentaire soit nécessaire, la télédétection offre potentiellement une amélioration de la programmation de l'irrigation.*

Mots-clés. *NDVI – Température radiative – Conductance stomatique - Potentiel hydrique foliaire de base PLWP.*

I – Introduction

Irrigation is one of the most costly factor for the Mediterranean agriculture. Traditionally, irrigation scheduling has been based on weather station observations (Caliandro and Mastrorilli, 2001), which lack both the crop water status and the continuous spatial variation needed to realize a precision irrigation.

Since the 1970's, hundreds of studies have used satellite land observation data to monitor a variety of dynamic land surface processes (e.g., Anderson *et al*., 1976; Reed *et al*.,1994; Yang *et al*., 1998; Peters *et al*., 2002). Satellite remote sensing provides a synoptic view of the land and a spatial context for the correct management of irrigation at the district scale. Remote measurements of canopy temperature and the normalized difference vegetation index (NDVI) can be used for monitoring the crop water status and scheduling correctly the irrigation.

Radiative canopy temperature has been successfully used to time irrigation applications for well-watered crop growing conditions. The cumulative daily time that canopy temperature exceeds a crop specific temperature threshold is used to indicate the need for irrigation (Wanjura *et al*., 2003).

NDVI, which is the normalized reflectance difference between the near infrared (NIR) and visible red bands (Rouse *et al*., 1974; Tucker, 1979) is used extensively in ecosystem monitoring. The NDVI measures the changes in chlorophyll content (via absorption of visible red radiation) and in spongy mesophyll (via reflected NIR radiation) within the vegetation canopy. As a result, higher NDVI values usually represent greater vigour and photosynthetic activity (or greenness) of vegetation canopy (Tucker, 1979; Chen and Brutsaert, 1998). NDVI's role in water balance monitoring and assessment has been described several times during the last decade (Kogan, 1991; Kogan, 1995; Yang *et al*., 1998; McVicar and Bierwirth, 2001; Ji and Peters, 2003; Wan *et al*., 2004).

However, one limitation of remote sensing signals for scheduling the irrigation is the contemporary presence of both desiccated and wetted zone in the irrigated plots. This is typical of the irrigated row crops of the Mediterranean area.

The objective of this study is to estimate water status on the territorial level by obtaining these estimates for an entire district (Rinaldi *et al*., 2006a, and 2006b).

II – Materials and methods

To verify if remote sensing techniques are a possible tool for estimating crop water status, in 2007 a measurement campaign was carried out in Rutigliano (lat. 41°01' N, long. 17°01 E, alt. 147 m a.s.l.), at the CRA-SCA experimental farm, with the tomato as the reference crop. After the tomato crop attained the maximum LAI value (2.89) and the canopy covered the ground (>90%), it was subjected to three irrigation treatments (fig. 1): one was optimal, and the other two underwent "temporary" stress (early, at the setting of the fruit, and late, at its ripening). Irrigation was scheduled whenever PLWP reached -0.3 and -0.5 MPa, in full irrigated and stressed plots, respectively. However, the latter value of PLWP does not compromise the tomato growth.

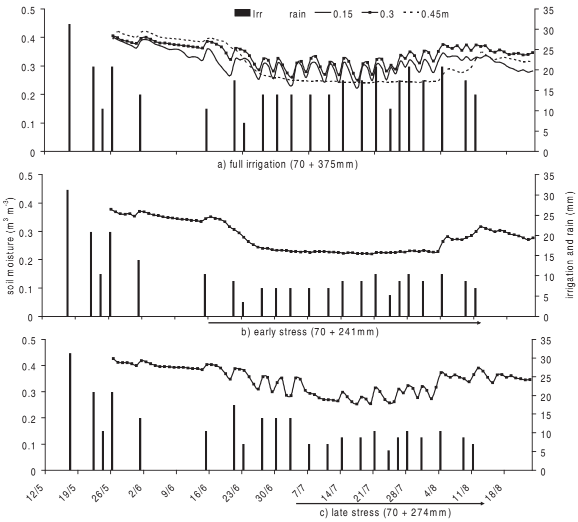

Figure 1. Soil moisture measured by the TDR technique at -0.15, -0.30 and -0.45m in a), and at -0.30m in b) and c). Amounts of irrigation (solid) and rain (dashed) are represented by vertical lines. Arrows in b) and c) indicate the temporary stress periods.

To monitor the water status, both ‘remote sensing’ (NDVI and radiative surface temperature) and ‘manual’ measurements (stomatal conductance and pre-dawn leaf water potential) were used. NDVI was monitored (each 10 minutes) through the sensor SKR 1800, as:

$$NDVI = \frac{\rho_{NIR} - \rho_{Red}}{\rho_{NIR} + \rho_{Red}}$$

where ρ represents the ratio between reflected and incident radiations at two wave-length: Red (646 nm) and NIR (831 nm).

Surface canopy temperature was hourly measured through infra-red sensors (Everest Interscience Inc., USA, model 4000.4ZXL), placed at 1m above the vegetation surface.

Stomatal conductance was measured at noon (in not cloudy days) by a porometer (Delta T instruments, UK) and the pre-dawn leaf water potential (Ψ) was measured by the Scholander pressure chamber.

III – Results and discussions

The soil water status, above all for crops irrigated in rows, is difficult to define exactly. As shown in figure 2, the horizontal variability is quite high.

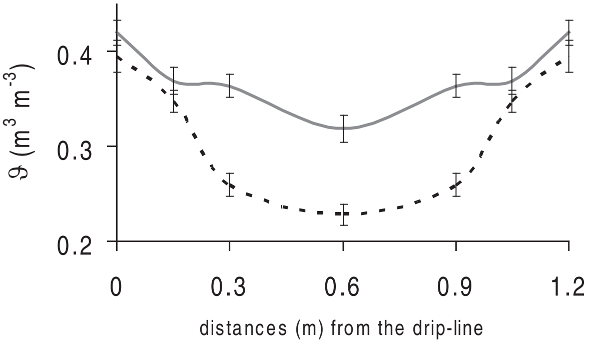

Figure 2. Volumetric moisture (at -0.3m depth) measured during the tomato season in the transect between two contiguous drip-lines under two water regimes: full irrigation (solid line) and stress (dashed line).

The indications acquired through remote sensing distinguish with precision neither the horizontal nor the vertical variations in humidity. Measurement of the crop water status (fig. 3), expressed through the maximum daily value of leaf water potential (Ψ) is affected by fewer errors because it is measured at “pre-dawn” (before sunrise), when the soil water status and the crop water status are in equilibrium. Measurements of PLWP have four advantages:

a) they are not influenced by the meteorological condition;

b) they integrate the variations in humidity that normally characterise the soil;

c) they are correlated to the water available in the soil (fig. 4);

d) they are correlated to the stomatal conductance (fig. 5).

For the purposes of irrigation management, the monitoring of PLWP allows for the scheduling of the irrigation and the prevention of stomatal closure. In other words, it allows to correctly follow the 'regulated deficit irrigation' (RDI), for saving irrigation water and maintaining crop productivity.

The main limitation in the use of the PLWP lies in the laboriousness of the method, such that it can not be extended to agricultural practice or to the estimation of water budgets through remote sensing. An alternative solution is to derive the crop water status by 'automatic' and, above all, 'remote sensing' measurements. Radiative temperature and NDVI have these characteristics.

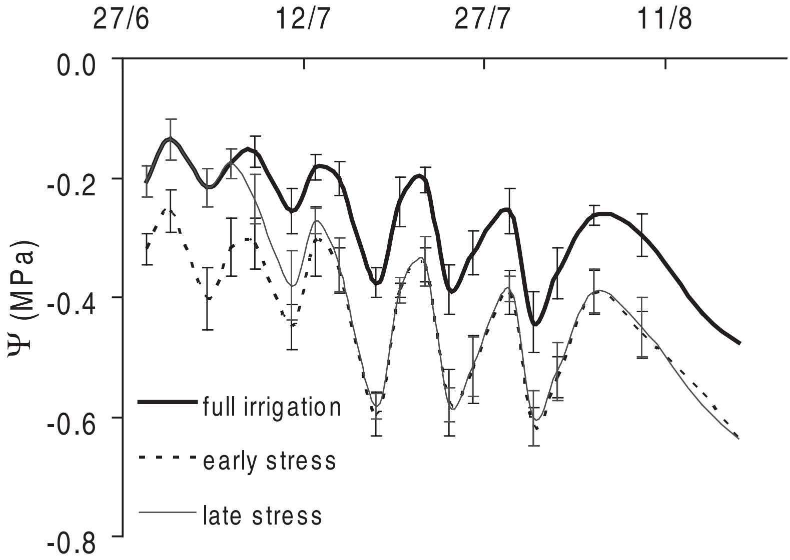

Figure 3. Daily variations in pre-dawn leaf water-potential (Ψ) during the tomato cycle grown under three water regimes.

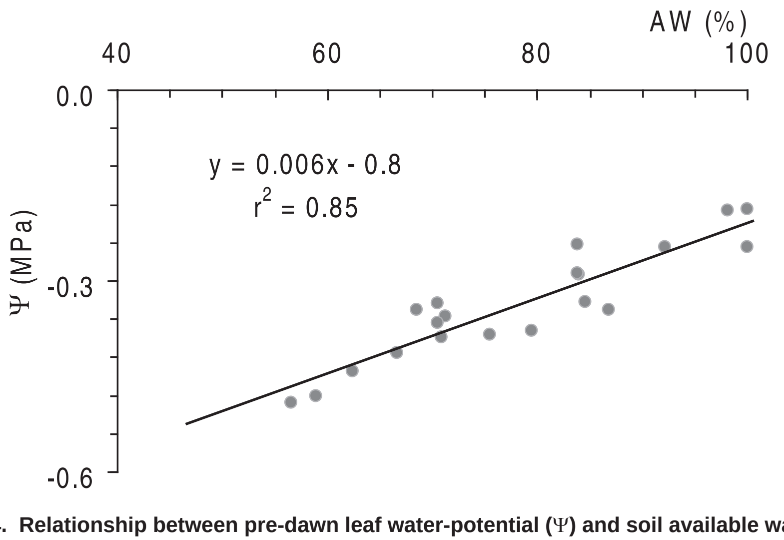

Figure 4. Relationship between pre-dawn leaf water-potential (Ψ) and soil available water (AW).

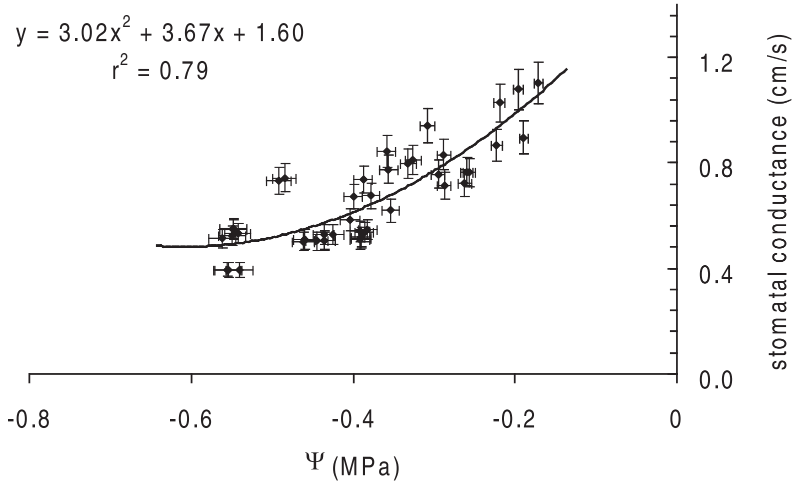

Figure 5. Relationship between stomatal conductance and pre-dawn leaf water-potential (Ψ).

The NDVI index varies during the crop cycle (fig. 6) following the crop growth (LAI and biomass). It should be underlined that the stress was applied after the maximum LAI value. Respect to the 'full irrigation' treatment, a reduction of the seasonal irrigation volume (-36% and -27% in early and late 'temporary stress' treatments, respectively) did not compromise the tomato growth.

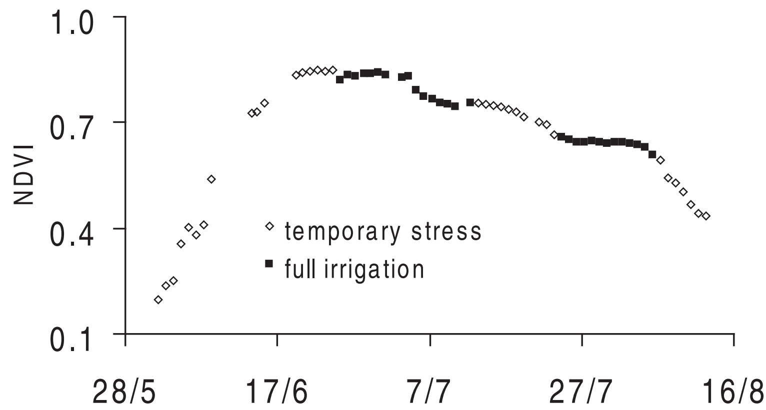

Figure 6. Variations of NDVI measurements during the tomato crop season. The different symbols stand for the two irrigation treatments. Each experimental point represents the average of the daily NDVI values measured in the time interval between 8 a.m. and 5 p.m..

Nevertheless between PLWP and NDVI a linear relationship results: $\Psi = 1.67 \cdot NDVI - 1.59$; $r^2 = 0.95$ (fig. 7). From this relationship it seems possible to predict the crop water status starting from completely automatic measurements and, above all, from those ones that can be acquired through remote sensing techniques.

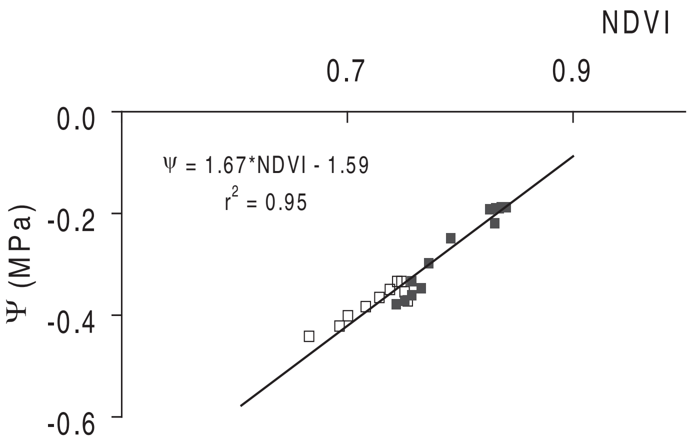

Figure 7. Pre-dawn leaf water-potential (Ψ) *vs* daily values of NDVI. Values derive from the full-irrigation (solid symbols) and the stressed (unfilled symbols) treatments.

Vice versa, the measurements of radiative temperature used to estimate the water status of the tomato proved to be unsatisfactory (fig. 8). The temperature of the vegetation, besides the soil water regime, is dependent on the meteorological conditions at the time of measurement.

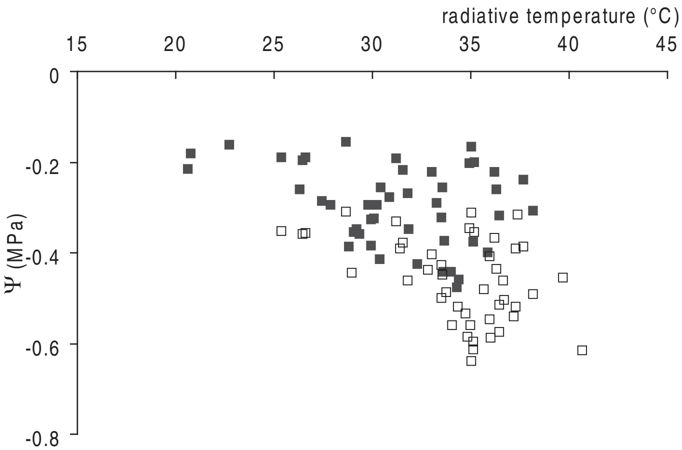

Figure 8. Pre-dawn leaf water-potential (Ψ) *vs* radiative temperature (maximum daily values). Unfilled symbols represent the measurements on the stressed tomato and solid symbols the measurements on the full-irrigated tomato.

IV – Conclusions

Continuous measurements of water status of crop let possible to schedule irrigation with the highest precision (Clarke, 1997). Mainly in the Mediterranean regions the precision is required to use efficiently the water resources at field and regional levels. The first results of this work in progress support the hypothesis of identifying the water status of vegetation (PLWP) upon the relationship based on NDVI data.

Aknowledgments

This study was realized within the activities of the AQUATER project, funded by the Italian Ministry of Food, Agriculture and Forestry Policies (under contract n. 209/7393/05).

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