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Relation between precision remote sensing and water relations and gas exchange parameters in 'Verna' lemon

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SUMMARY – This work is part of the ongoing research being carried out in IMIDA experimental plots for the improvement of irrigation methods used in agriculture in the region of Murcia, contributing significantly to better drought management. Research focused on the correlation of physical variables collected in a plot of citrus trees with data of high-resolution near-infrared images. Values obtained by this correlation help us to automate tasks aimed at estimating the water status of other plots. This study concentrates on minimizing the impact of water shortages in the region of Murcia, which is very sensitive to drought, and on improving the agricultural systems in the region.

Key words: Remote sensing, drought, water relations, gas exchange, infrared, lemon tree.

RESUME – *"Relation entre la télédétection de précision et les paramètres de relations hydriques et d'échanges gazeux chez le citronnier 'Verna'". Cette étude fait partie des recherches que nous menons dans les parcelles expérimentales de l'IMIDA concernant l'optimisation des méthodes d'irrigation des cultures irriguées de la région de Murcie, dans le but d'améliorer la gestion de la sécheresse. Le travail a porté principalement sur la corrélation entre les variables physiques mesurées en plein champ dans une parcelle d'agrumes et les données apportées par des images proche infrarouge à haute résolution. Les informations obtenues nous aident à automatiser des tâches faisant partie des processus d'estimation de l'état hydrique d'autres parcelles. Le but de l'étude est de réduire au minimum les effets de la pénurie d'eau dans une zone comme la nôtre, spécialement sensible aux processus générés par la sécheresse, ainsi que d'améliorer les systèmes agricoles appliqués dans notre territoire.*

Mots-clés : *Télédétection, sécheresse, relations hydriques, échanges gazeux, infrarouge, citronnier.*

Introduction

Agriculture is highly sensitive to drought, especially in southeastern Spain, a region characterized by a semi-arid climate. Since the scarcity of water has become the limiting factor of agricultural production in our area, the present work focuses on the characterization of water stress in citrus groves. Citrus is indeed one of the most important crops in Spain and one of the most important exports.

In recent years there has been a rapid development in terrestrial remote sensing systems, with the emergence of new sensors offering better performances, which has helped to improve research on the coverage of the Earth's surface. In the agricultural sector, these tools have contributed to the advancement of precision farming, improving the agricultural aspects, reducing the environmental impacts associated with agricultural activities and optimizing production costs.

In this study, we intend to correlate data from high-resolution near-infrared images with field values characterising the physiological status of the plants, and thus learn which of these parameters present a stronger relationship with this part of the electromagnetic spectrum.

Materials and methods

Work was carried out in one of the experimental plots of our Institute located in the communal area of Torre-Pacheco (southeast of the Murcia region) (Fig. 1). The 2 ha plot was planted with 7-year old lemon trees of the 'Verna' variety, grafted on sour orange trees and on *Citrus macrophylla* with a 5 x 4 m planting pattern. Two irrigation treatments were established: A control treatment (100 % ETc) and a treatment where irrigation was interrupted for 50 days until plants reached severe water stress. Irrigation resumed normally after this period of stress.

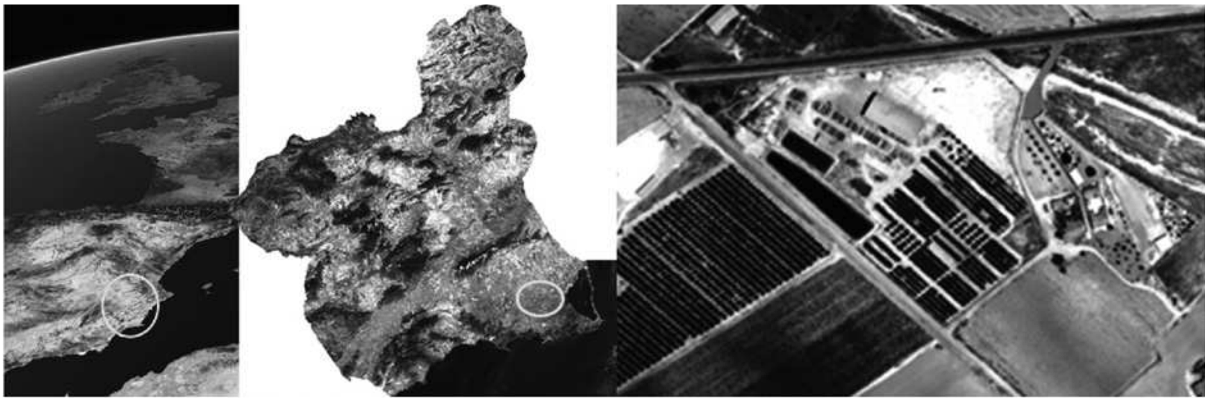

Fig.1. Location and situation of the experimental plot.

To control the water status of the plant, the xylem water potential and the gas exchange parameters were measured at the time of peak water stress. Xylem water potential was determined using a pressure chamber (Scholander, 1965), taking 4 measurements per tree in the four cardinal directions. Gas exchange parameters were determined by a LiCor 6400 analyzer together with a red/blue light source (6400-02B LED). In order to check the field values, a near-infrared aerial photograph was taken the same day the data was collected in the plots. A Leica ADS40 camera carried by a Partenavia P68C aircraft was used to acquire the image, which had a spatial resolution of 35 cm per pixel and a radiometric resolution of 16 bits. The statistical analysis of the results was performed using the Statgraphics 5.1 Plus package.

Results and discussion

Interruption of irrigation caused a decrease of the xylem water potential (ψ_x), leading to severe water stress. The most important differences between treatments were reached after 50 days without irrigation. ψ_x values were significantly lower in bitter orange (-2.5 MPa) than on *C. macrophylla* (-1.82 MPa) rootstocks (Table 1). ψ_x values for the control treatment were similar in both control stocks. The levels of water stress observed in both rootstocks of the drought treatment are mainly due to different degrees of tolerance to drought, a fact which has already been described. With regard to the values of gas exchange, at the end of the period of water stress the net photosynthesis rate (P_{net}), the stomatal conductance (g_s), and the transpiration rate (E) were significantly lower in trees of the drought treatment (Table 1). In contrast with the differences observed in the water status of the two rootstocks, the gas exchange parameters showed no significant differences between rootstocks, but a strong effect of the drought treatment.

At the time of peak water stress, the levels of red, green and blue of the visible spectrum showed no significant differences, neither for the drought treatment nor for the rootstock (Table 2). However, the study of the combination bands in the visible spectrum demonstrated a significant effect of drought treatment in the red-green region, showing higher levels in both rootstocks than in the control treatment (Table 3). Higher values for the red-green combination band in drought-stressed trees indicate a less green coloration. Therefore, it is possible that severe water stress causes a hue shift in the leaf mass of the 'Verna' lemon tree that could be detected by analysing the visible red-green combination band.

With regard to the levels in the near-infrared region of the spectrum (IR_{near}), significantly lower values were observed in the drought-stressed trees, for both rootstocks. However, differences among treatments were more pronounced in *Citrus macrophylla* than in bitter orange trees (Table 2).

Table 1. Values of xylem water potential and gas exchange parameters [net photosynthesis rate (P_{net}), stomatal conductance (*gs*), and transpiration rate (*E*)] in 'Verna' lemon trees grafted on two rootstocks (bitter orange tree and *Citrus macrophylla*) exposed to 50 days of drought treatment

		ψ_x *(MPa)*	P_{net} *(μmol CO_2 m^{-2} s^{-1})*	g_s *(mol H_2O m^{-2} s^{-1})*	*E* *(mmol H_2O m^{-2} s^{-1})*
B. orange	Control	-0.98 a	2.66	0.06	2.34
B. orange	Drought	-2.50 c	0.35	0.02	1.02
C. macrophylla	Control	-0.94 a	3.28	0.07	2.65
C. macrophylla	Drought	-1.82 b	0.52	0.03	1.32
ANOVA					
Rootstock		**	ns	ns	ns
Treatment		***	***	***	***
Rootstock x Treatment		**	ns	ns	ns

Each value is the average of 10 replications. *, **, *** and ns indicate significant differences at P <0.05, P <0.01 and P <0.001 and not significant differences, respectively. For each column, different letters indicate significant differences at 95% according to the Duncan's Multiple Range test.

Table 2. Levels of visible spectrum and near-infrared (IR_{near}) radiation of 'Verna' lemon trees grafted on two rootstocks (bitter orange tree and *Citrus macrophylla*) exposed to 50 days of drought treatment

		Visible			IR_{near}
		Red	Green	Blue	
B. orange	Control	3503	3789	3014	6535 b
B. orange	Drought	3625	3770	3041	6441 bc
C. macrophylla	Control	3460	3691	2972	6664 a
C. macrophylla	Drought	3645	3745	3063	6406 c
ANOVA					
Rootstock		ns	ns	ns	ns
Treatment		ns	ns	ns	***
Rootstock x Treatment		ns	ns	ns	*

Each value is the average of 10 replications. *, **, *** and ns indicate significant differences at P <0.05, P <0.01 and P <0.001 and not significant differences, respectively. For each column, different letters indicate significant differences at 95% according to the Duncan's Multiple Range test.

Furthermore, it is necessary to know which of the bands obtained by aerial photography reflects more accurately the plant water status parameters. We conducted a stepwise multiple regression analysis between remote sensing data (visible spectrum and IR_{near}) and field data (water potential and gas exchange parameters) (Table 4) (Brancadoro, 2006). In the model obtained for ψ_x, the IR_{near} band explained 56% of the variance of this parameter, while the model was only slightly improved following the addition of the visible red band. As to P_{net} and g_s, the gas exchange parameters, the IR_{near} band explained respectively 63% and 71% of their variance. In both cases, the model was only slightly improved (by 3%) with the addition of the combination bands in the red-green visible spectrum. Finally, in the model obtained for *E,* the IR_{near} band explained 71% of the variance. Adding the visible blue band improved the model by a significant but marginal 3%. In all cases, the addition of the IR_{near} band helped for the most part to predict the variance in the plant water status indicators, and the models improved slightly with the addition of some of the bands in the visible spectrum, especially the red-green combination bands. In conclusion, IR_{near} measurements, together with the red-green combination bands in the visible spectrum, were shown to be sensitive enough for detecting changes in the water status of drought-stressed 'Verna' lemon trees. Therefore, the combined use of these parameters could be a fast and useful tool for irrigation scheduling of 'Verna' lemon trees.

Table 3. Levels of combination bands in the visible spectrum of 'Verna' lemon trees grafted on two rootstocks (bitter orange tree and *Citrus macrophylla*) exposed to 50 days of drought treatment

		Combination bands (visible spectrum)		
		Brightness	Red-green	Blue-yellow
B. orange	Control	10305	-286	-3300
B. orange	Drought	10436	-145	-3186
C. macrophylla	Control	10124	-231	-3203
C. macrophylla	Drought	10453	-100	-3162
ANOVA				
Rootstock		ns	ns	ns
Treatment		ns	*	ns
Rootstock x Treatment		ns	ns	ns

Each value is the average of 10 replications. *, **, *** and ns indicate significant differences at P <0.05, P <0.01 and P <0.001 and not significant differences, respectively. For each column, different letters indicate significant differences at 95% according to the Duncan's Multiple Range test.

Table 4. Stepwise multiple regression analysis between the parameters indicating plant water status and the radiation levels in the visible and near-infrared spectrum in a grove of 'Verna' lemon trees grafted on two rootstocks (bitter orange tree and *Citrus macrophylla*). Only significant (P<0.05) regressions are shown

Dependent variable	Step	Equation	Correlation coefficient
Xylem water potential	1	$\psi_x = -17.6 + 0.0025IR_{near}$	r = 0.54***
	2	$\psi_x = -14.7 + 0.0025IR_{near} - 0.001V_{red}$	r = 0.62***
Net photosynthesis rate	1	$P_{net} = -43.9 + 0.007IR_{near}$	r = 0.63***
	2	$P_{net} = -44.4 + 0.007IR_{near} - 0.003V_{red\text{-}green}$	r = 0.68***
Stomatal conductance	1	$g_s = -0.74 + 0.0001IR_{near}$	r = 0.71***
	2	$g_s = -0.74 + 0.0001IR_{near} - 3.4E\text{-}5V_{red\text{-}green}$	r = 0.73***
Transpiration rate	1	$E = -24.4 + 0.004IRnear$	r = 0.71***
	2	$E = -15.7 + 0.004IRnear - 0.002V_{blue}$	r = 0.74***

*, **, *** and ns indicate significant differences at P <0.05, P <0.01 and P <0.001 and not significant differences, respectively.

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