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Study of the effects of irrigation on stem water potential and multispectral data obtained from remote sensing systems in woody crops

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Abstract. This study is part of the work carried out in experimental plots of different research centres (IMIDA, CEBAS, UPCT and IVIA) that are part of the TELERIEG project, with the aim of improving irrigation methods in irrigated crops in the region of Murcia, significantly contributing to a better management of drought. The work was carried out, on the one hand, on two parcels of citrus fruit (mandarin and grapefruit) where several different irrigation treatments were applied, which generated varying degrees of water stress on the studied trees. Three sources of irrigation water were also used, each one different in nature and quality, in order to study their impact on the development of crops. On the other hand, work was also carried out on a parcel of peach trees, where several different irrigation treatments were applied, which also generated varying degrees of water stress. This variability in tree water status was measured in the field through stem water potential at midday (Ψs), and from the air by capturing images with a multispectral camera to estimate the values of the near-infrared spectrum (NIR) and the normalized difference vegetation index (NDVI).

Keywords. Precision agriculture – Remote sensing – Drought – Water relations – Reclaimed water irrigation.

Étude des effets de l'irrigation sur le potentiel hydrique de la tige et sur les données multispectrales obtenues par télédétection dans des cultures ligneuses

Résumé. *Cette étude s'inscrit dans le cadre des recherches effectuées dans des parcelles expérimentales de différents centres de recherche (IMIDA, CEBAS, UPCT et IVIA) participant au projet TELERIEG, dont l'objectif est l'amélioration des méthodes d'irrigation des cultures irriguées dans la région de Murcie, contribuant ainsi de façon significative à la gestion de la sécheresse. Les travaux ont été réalisés, d'une part, sur deux parcelles d'agrumes (mandarine et pamplemousse) où plusieurs traitements différents d'irrigation ont été appliqués, ce qui a généré des degrés variables de déficit hydrique sur les arbres étudiés. On a également utilisé trois sources d'eau d'irrigation de nature et qualité différentes, afin d'étudier leurs effets sur le développement des cultures. Les travaux ont été aussi conduits sur une parcelle de pêchers où plusieurs traitements différents d'irrigation ont été appliqués, ce qui a généré des degrés variables de déficit hydrique sur les arbres étudiés. Cette variabilité de l'état hydrique des d'arbres a été mesurée sur le terrain à l'aide du potentiel hydrique des tiges à midi (Ψs), et à distane au moyen d'images capturées avec une caméra multispectrale, qui ont permis d'estimer les valeurs du spectre dans le proche infrarouge (NIR) et l'indice de végétation par différence normalisée (NDVI).*

Mots-clés. *Agriculture de précision – Télédétection – Sécheresse – Relations hydriques – Irrigation avec des eaux recyclées.*

I – Introduction

Agriculture has always been influenced by various climatic elements. Among them, drought is one of those which affect more negatively the production and the quality of agricultural products, especially in South-East Spain, which is characterized by semi-arid climate. Therefore, the shortage of water for agriculture in this highly productive area periodically causes high losses that strongly affect the economy. This has led in the last decade to a major boom in the purification and reuse of reclaimed water in the Region of Murcia, a fact that highlights the importance of researching on the interaction of these low-quality waters with strategies of regulated deficit irrigation (RDI), especially in areas as South-East Spain, where water scarcity is a major issue. 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.

Based on these criteria, several studies have been conducted to evaluate the effects of regulated deficit irrigation in fruit trees. One of them has been based on the effect of water of different qualities on stem water potential in citrus; another one has characterized the physiological state of peach trees. In both cases the field values have been correlated with the evolution of some parameters obtained through terrestrial remote sensing systems, i.e. high-resolution images with near-infrared data.

II – Material and methods

The trials were conducted in the summer of 2009: the first one in two commercial farms located in Molina de Segura (Murcia, Spain) and the second one in a commercial farm located in Fuente Librilla, Mula (Murcia, Spain). All these plots have been under study within the Telerieg project (SUDOE programme), along with other trials that have been carried out in different experimental plots with various fruit trees and different treatments (Fig. 1).

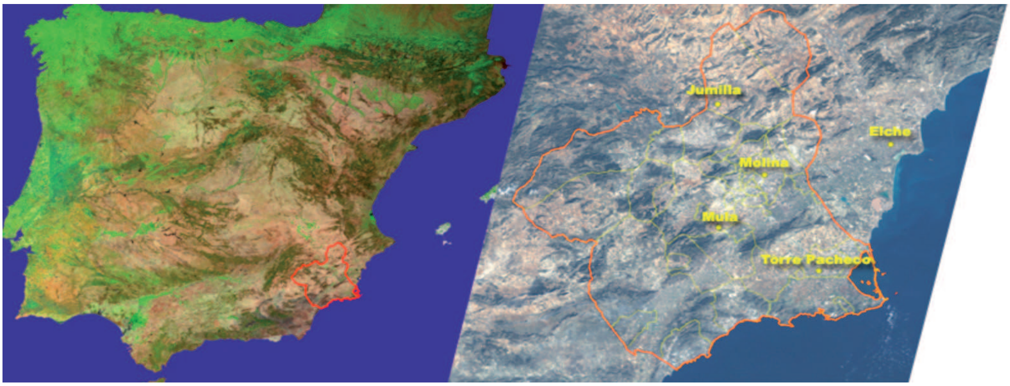

Fig. 1. Experimental plots under study within the Telerieg SUDOE project.

1. Study plots

The study on reclaimed water, conducted in Molina de Segura, was performed on two plots with different crops: a 4 years old grapefruit (cv. Star Ruby) grafted on macrophylla (Fig. 2) and a 7 years old mandarin (cv. Orogrande) grafted on Citrange carrizo (Fig. 3).

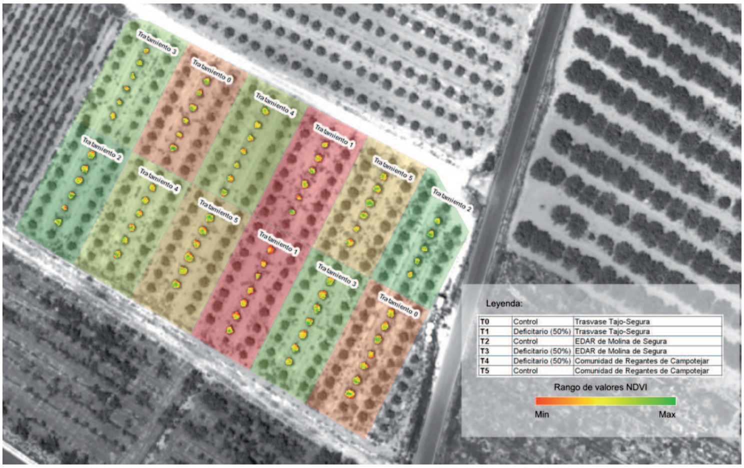

Fig. 2. Irrigation treatments on a grapefruit plot in Campotejar (Molina de Segura, Spain).

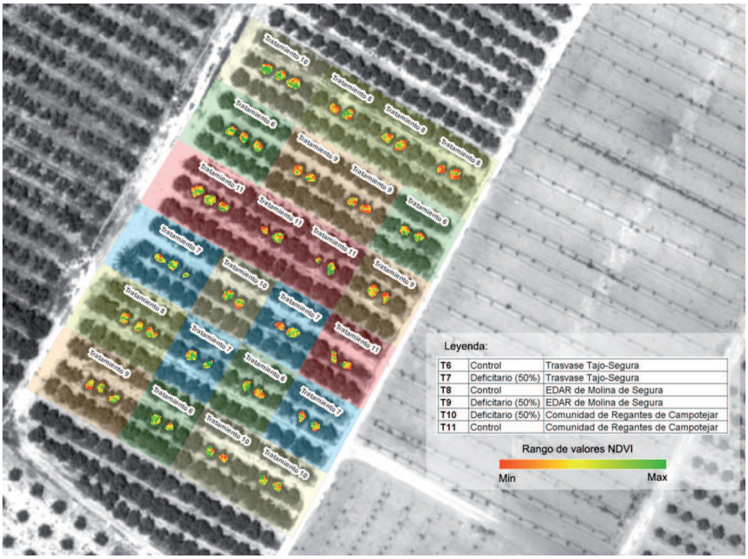

Fig. 3. Irrigation treatments on a mandarin plot in Campotejar (Molina de Segura, Spain).

Three sources of irrigation water were used: the first, from the Tajo-Segura Aqueduct, had a good agronomic quality; the second, from the WWTP of Molina de Segura, was mainly characterized by its high salinity; the third, from the Irrigation Community of Campotejar, was a blend of well water and purified wastewater used in different proportions depending on the availability of each one of them (Figs 2 and 3). Throughout the production cycle, the average value of the electrical conductivity (EC) of the different sources of water was of 1.2, 3.4 and 2.5 dS/m for aqueduct water, wastewater and community water, respectively.

Drip irrigation was used, with a single irrigation line for each row of trees and three emitters per plant, which had a rate of 4 l·h^{-1}. There were two irrigation treatments for each quality of water: a control where watering met crop requirements (100% ETc) and a RDI treatment where the volume of water was reduced to 50%, compared to the control treatment, during the second phase of fruit growth (from late June to mid-August).

Regarding the Fuente Librilla plot, the trial was conducted on adult peach trees (*Prunus persica* L. cv. Catherine) grafted on GF677, with a 6 × 4 m planting pattern. Drip irrigation was used, with a single irrigation line for each row of trees and five emitters per plant, which had a rate of 4 l·h-1.

The experimental plot was divided equally into five irrigation treatments: a control (C), which was watered to meet crop water requirements (100% ETc) and four RDI treatments were watering was reduced respectively 70%, 60%, 50%, and 40% compared to the control treatment. The RDI period went from May 5 to June 10, 2009. To perform the trial, 21 trees randomly distributed among the different irrigation treatments were monitored (Fig. 4).

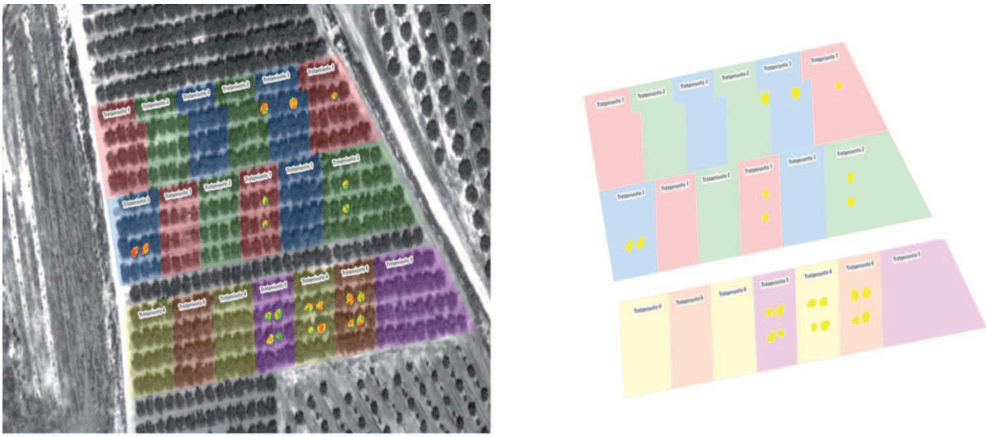

Fig. 4. Distribution of treatments and monitored trees in the experimental plot (commercial farm located in Fuente Librilla, Mula, Spain). Experimental design and aerial view.

2. Measured parameters

Both trials studied the effects of irrigation treatments on the water status of trees, aiming to establish correlations between physiological variables obtained in the field (stem water potential) and data from a series of high-resolution near-infrared images obtained through remote sensing systems.

Water status in field was determined by measuring the stem water potential at midday (Ψs) in healthy adult leaves close to the trunk, following the technique described by Scholander *et al.* (1965) and Turner (1988). A pressure chamber (Soil Moisture Equip. Corp., 3000 model, Santa Barbara CA, USA) was used as described by Hsiao (1990).

To obtain remote sensing imagery, a multispectral camera (ADS40) carried in an aircraft type Partenavia P68C was used. The resulting images had a spatial resolution of 35 cm per pixel and radiometric resolution of 16-bit sensor. The flight took place on August 14, 2009, coinciding with the field data collection.

The images from different plots were comprehensively analysed with GIS tools for obtaining infrared data. Monitored trees were mapped in the image by means of their coordinates, taken in the field with a GPS. Then, the perimeter of all crops was digitized to generate a cutting "mask" to extract data from images, but this was done after removing all outer pixels in order to minimize edge effect and leave out of the analysis the "noise" that could be produced by the "soil line" (Lychak *et al.,* 2000), i.e. values or information that do not correspond strictly to those we are looking for in the trees under study. Once these "mask" elements are better defined, we started the process of extracting data from the infrared (IR) spectrum of the captured images. This is how we obtained an index of normalized difference vegetation index (NDVI), a well-known and reliable index, backed up by numerous studies, that informs about the state of vegetation (Crippen, 1990).

Correlations between the different irrigation treatments and the various parameters measured were done through a series of statistical analysis based on the use of SPSS and R software applications.

III – Results and discussion

1. Mandarin trees

The results show that regulated deficit irrigation affected the stem water potential (Ψs) of mandarin trees, the control trees always showing higher values than those subjected to water deficit. Using the Mann–Whitney U test to compare the results obtained with different watering treatments in mandarin (control and RDI), we observed that Ψs was the only variable significantly affected by the volume of water supplied (U=2.5 p=0.001) (Table 1).

Table 1. Mann-Whitney U test for different watering treatments (control and deficit irrigation) on mandarin trees

	Ψ_s	NIR	NDVI
Mann-Whitney U	2.500	37.000	40.000
Asymp. Sig. (2-tailed)	0.001	0.757	0.965

Using the Kruskal-Wallis test, it was observed that the NDVI showed significant variations depending on the quality of water used in the different treatments. This test was supplemented later by a new one (NPar test; Field, 2009), which allowed us to find pair relationships. As a result of this analysis, no significant differences were observed in the NDVI between trees irrigated with water of good quality (Tajo-Segura Aqueduct) and water of intermediate quality (Irrigation Community) (Table 2). However, significant differences in NDVI were found between trees irrigated with water from the aqueduct and from the WWTP (Table 3). Finally, there were also significant differences in the NDVI between trees irrigated with low-quality water (WWTP) and those irrigated with water of intermediate quality (Irrigation community) (Table 4).

Table 2. Mann-Whitney U test for different water sources (Tajo-Segura Aqueduct and Irrigation Community) on mandarin trees

	Ψ_s	NIR	NDVI
Mann-Whitney U	10.000	5.500	13.000
Asymp. Sig. (2-tailed)	0.195	0.045	0.423

Table 3. Mann-Whitney U test for different water sources (Tajo-Segura Aqueduct and WWTP) on mandarin trees

	ψ_s	NIR	NDVI
Mann-Whitney U	12.500	10.000	4.000
Asymp. Sig. (2-tailed)	0.375	0.200	0.025

Table 4. Mann-Whitney U test for different water sources (Irrigation Community and WWTP) on mandarin trees

	ψ_s	NIR	NDVI
Mann-Whitney U	15.000	9.000	5.000
Asymp. Sig. (2-tailed)	0.626	0.150	0.037

2. Grapefruit trees

Deficit irrigation treatments on grapefruit trees generated, as was the case in mandarin trees, significant differences in stem water potential, Ψs values in control treatments being higher compared to deficit treatments. Also, just like it was observed on mandarin trees, grapefruit trees irrigated with water of different quality showed significant differences in one of the studied variables, near-infrared (NIR) in this case.

To validate this information, we used the Shapiro-Wilk and Levene test, which showed that different quantities and qualities of water affected the dependent variables Ψs, NIR and NDVI (Table 5).

Table 5. Mann-Whitney U test for different water treatments (control and deficit irrigation) and water sources (Tajo-Segura Aqueduct, Irrigation Community and WWTP) on grapefruit trees

	Variable	Sum of Squares	df	Mean Square	F	Sig.
Quantity of water	ψ_s	35.042	1	35.042	34.800	0.000
	NIR	21420.375	1	21420.375	0.333	0.571
	NDVI	1137663630.042	1	1137663630.042	2.392	0.139
Quality of water	ψ_s	5.396	2	2.698	2.679	0.096
	NIR	457534.750	2	228767.375	3.559	0.050
	NDVI	1776264131.396	2	888132065.698	1.867	0.183

The results in Table 5 clearly show that the quantitative treatments had a significant impact on Ψs ($F=34.800$; $p<0.00$), while qualitative treatments significantly affected the NIR variable ($F=3559$; $p=0.05$). Finally, the interaction effect, i.e. the combined effect of quantity and quality of water was not significant for any of the variables considered.

As it was done in mandarin trees, the effect of water quality was analysed statistically considering differences between pairs, and thus it was observed that the NIR was significantly different between grapefruit trees irrigated with water from the Tajo-Segura Aqueduct (good quality) and those irrigated with water from the WWTP and the Irrigation Community (intermediate and low quality respectively), but did not differ between trees irrigated with community or WWTP water (Fig. 1).

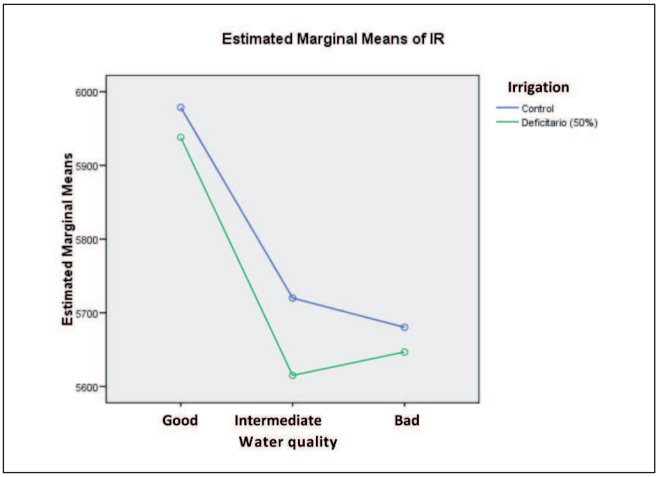

Fig. 1. Degree of discrimination between NIR values, considering the quantity of water and its quality, on grapefruit trees.

3. Peach trees

In the trial carried out on peach trees it could be observed, as shown by the Mann-Whitney test, that there were significant differences between different irrigation treatments for values of stem water potential (Ψs), near-infrared (NIR) and normalized difference index (NDVI) (Table 6).

Table 6. Results of Mann-Whitney test

	ψ_s	NIR	NDVI
Mann-Whitney U	0.0	12.0	13.0
Wilcoxon W	66.0	67.0	68.0
Z	3.87	3.02	0.95
Asymp. Sig. (2-tailed)	0.000	0.002	0.003
Exact Sig. (2-tailed)	0.000	0.002	0.002
Exact Sig. (1-tailed)	0.000	0.001	0.001
Point probability	0.000	0.000	0.000

Table 7. Table of correlations between various parameters

	ψ_s	NIR	NDVI	
ψs	Pearson Corr.	1	0.610††	0.746†
	Signif.		0.003	0.000
	N	21	21	21
NIR	Pearson Corr.	0.610†	1	0.752†
	Signif.	0.003		0.000
	N	21	21	21
NDVI	Pearson Corr.	0.746†	0.752††	1
	Signif.	0.000	0.000	
	N	21	21	21

† Correlation is significant at 0.01 (bilateral).

An average (r=0.61) significant correlation was found between Ψs and NIR, and a strong one (r=0.74) between Ψs and NVDI. There was also a high correlation between NIR and NDVI (r=0.75), but this was expected, since both variables are based on near-infrared data.

IV – Conclusions

It should be noted that both the values of stem water potential and the remote sensing parameters used in our study on citrus trees give us complementary information about the behaviour of trees under different irrigation treatments. Deficit irrigation led to temporary and limited changes in the water status of the trees that were shown by the decrease of stem water potential at the time of sampling. However, using water of different quality over a long period of time produced significant changes in multispectral data (NIR) recorded in trees.

As for the peach study, we conclude that the three considered indices (Ψs, NIR, NDVI) were sensitive to the degree of water deficit generated in the trees. These indices showed significant correlation values when compared two-by-two. The best correlation was found between the two parameters obtained from multispectral data analysis (NIR and NVDI), whereas stem water potential (Ψs) presented a better correlation with NVDI than with NIR.

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