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Water Productivity and Fruit Quality in Deficit Drip Irrigated Citrus Orchards

Ana Quiñones, Carolina Polo-Folgado, Ubaldo Chi-Bacab,
Belén Martínez-Alcántara and Francisco Legaz
Instituto Valenciano de Investigaciones Agrarias, Moncada (Valencia)
Spain

1. Introduction

Citrus is one of the most relevant crops worldwide with a yearly average production of $90 \cdot 10^6$ Mg in the last decade. In Mediterranean countries, citrus is the second largest fruit crop after apples, in the European Union (EU). Spain is the leading producer in the area with nearly 60 % of tonnes produced in the whole of the EU (Ollier et al., 2009). In Spain, citrus orchards cover around $300 \cdot 10^3$ ha ($6 \cdot 10^6$ Mg) of which up to 60 % is located in the Comunidad Valenciana (CV). This area has remained more or less constant in this respect since 1990 (MARM, 2010). The Comunidad Valenciana is the most important region, not only in acreage but also with respect to its long tradition of citrus farming.

In this area, like in many regions of the world, the lack of water or lack of good water is a growing concern for the development of relevant agriculture since water is the most limiting factor for crop production. Moreover, climatic conditions are characterized by low rainfall (400-600 mm year-1) and irregular spatial and temporal distribution. On the other hand, the world's population has undergone an exponential growth, which has led to soaring food demand and, therefore, high natural-resource exploitation. For example, in Spain, irrigated land had risen up to 3.421.304 ha in 2009 (MARM, 2010).

Therefore, improved water use efficiency (WUE) or water productiviy (WP), using different strategies, is a key concept to solve this water scarcity. So nowadays, efforts are being focussed on developing not only alternative irrigation methods but also new water management methods in order to reduce water dosages while maintaining maximum tree growth, without significantly affecting yield.

2. Options for improving irrigation efficiency

Wallace and Batchelor (1997) showed the main options for improving WUE in different categories, engineering, agronomy, management and institutional improvements. Although it is not possible to discuss all the options listed in detail by these authors, three of the options are of particular interest.

Concerning engineering improvements, there are several irrigation systems to water crops that can reduce application losses and improve application uniformity.

In flood irrigation, a large amount of water is directed to the field and flows over the ground among the crops. In regions where water is abundant, flood irrigation is the cheapest irrigation method and this low tech irrigation method is commonly used in developing countries. On the contrary, localized irrigation is a system where water is distributed under low pressure through a piped network, in a pre-determined pattern, and applied as a small discharge to each plant or adjacent to it. Regarding irrigation systems, in the citrus area of Spain, about 69 % of citrus orchards are irrigated under fertigation, mainly with drip irrigation, and the remaining by flood irrigation (MARM, 2010). Similar percentages are found in other citrus areas where localized (drip or mini-sprinklers) irrigation systems are mainly used for citrus and other tree crops (olives and deciduous trees), while sprinkler irrigation is dominant for fodder crops and some vegetables.

Depending on the different localized irrigation system fertigation can be performed on surface or subsurface drip, spray, micro-jet and micro-sprinkler. These different techniques can be used, both in annual crops or fruit trees, according to soil type and the different characteristics of agricultural area. This versatility has led to a rapid expansion of fertigation in the world cultivated areas. The advantages of fertigation are listed below (Burt et al ,1998).

- High water and nutrient use efficiency as a consequence of coupling fertilizer timing to the plant requirements and, therefore, minimized fertilizer/nutrient loss due to localized application and reduced leaching.
- Reduced energy cost by the saving of labour and machinery and the efficient use of the costly chemicals to be applied.
- Minimized soil erosion by avoiding heavy equipment traffic through the field to apply fertilizers.

Moreover, fertigation allows safe use of recycled or saline water. Boman et al., (2005) affirmed that irrigation scheduling is a key factor in managing salinity. Increasing irrigation frequency and applying water exceeding the crop requirement are recommended to leach the salts and minimize their concentration in the root zone. Fertigation also reduces the risk of diseases since foliage remains dry. Schumann et al., (2009) observed a significant reduction in the number infected trees of citrus greening disease or citrus canker by optimising daily and nutrient levels for trees. Moreover, frequent and small water split with fertigation technique leads to a shallow and compact root system in comparison with a wide and deeper root system in flood irrigated trees (Sne, 2006), enhances N uptake efficiency by the fibrous roots and contributes to lower leaching below the root zone (Quiñones et al., 2007).

In drip irrigation systems, subsurface drip irrigation (SDrI) has been part of modern agriculture. Current commercial and grower interest levels indicate that future use of SDrI systems will continue to increase. SDrI applies water below the soil surface, using buried drip tapes (ASAE, 2001). SDrI uses buried lateral pipelines and emitters to apply water directly to the plant root zone. Laterals are placed deep enough to avoid damage by normal tillage operations, but sufficiently shallow so that water is redistributed in the active crop root zone by capillarity. SDrI systems must be compatible with the total farming and cultural systems being used.

SDrI requires the highest level of management of all microirrigation systems to avoid remedial maintenance. A poorly designed SDrI system is much less forgiving than an improperly designed surface drip system. Deficiencies and water distribution problems are difficult and expensive to remedy. Lamm and Camp (2007) present an excellent, detailed review of SDrI.

These systems require safeguards and special operational procedures to prevent plugging and facilitate maintenance, but they also have numerous advantages. These were:

- The top of the soil surface remains dry, limiting surface evaporation to the rate of vapour diffusion transport and preventing salt accumulations on the surface.
- The use of a very high irrigation frequency (several times per day) that matches actual crop water use will result in a constant wetted soil volume and a net upward hydraulic gradient, which minimizes leaching.
- Supplying water and nutrients directly to the root zone allows root uptake to be more efficient if irrigation and fertilization schedules are appropriate.
- Soil crusts, which may impede infiltration and cause ponding and runoff, are bypassed so that surface infiltration variability becomes insignificant.

Under proper management, appropriately designed and managed SDI irrigation systems offer several other advantages to growers (Devasirvatham, 2009) because of their potential for:

- Maintaining access to fields with tillage, planting, spray and harvest equipment that is not restricted by irrigation.
- Obtaining better weed suppression with minimal chemicals because there is less seed germination with dry soil surfaces.
- Efficiently and safely applying labelled plant-systemic pesticides and soil fumigants for improved disease and pest control.
- Reducing surface wetting often reduces fungal disease incidence (e.g., molds, mildews) by maintaining dryer plant surfaces and lower air humidity within the plant canopy.
- Reducing pesticide exposures for workers when chemicals are applied below the soil surface.
- Implementing minimum tillage, permanent beds, and multiple cropping systems (Bucks et al., 1981), although much of the necessary equipment modifications and farming techniques have yet to be developed; and minimizing flow-rate sensitivity to temperature fluctuations because emitters are buffered by the soil.

Phene et al. (1992) and Phene (1995) listed several drawbacks, including potentially high initial system costs, potential rodent damage, the fact salt may accumulate between drip lines and soil surface, low upward water movement in coarse-textured soils, high potential for emitter plugging, and insufficient technical knowledge requiring dissemination, and hands-on experience by growers and researchers. In addition, fertility management becomes more critical with SDI because roots tend to grow deeper than with surface drip systems and some surface applied nutrients may not be sufficiently available (Phene, 1995).

Improved WUE can also be affected by water regimes. Although WUE frequently decreases under water deficit conditions (García Tejero et al. 2011), in areas with significant water scarcity, like in the east of Spain, it is possible to increase efficiency under different irrigation management methods based on deficit-irrigation (DI) programmes (Bonet et al. 2010). These DI strategies are defined as a practise where the total water provided for the plant (irrigation plus effective rainfall) is below to the crop's water needs (García-Tejero, 2010) in order to reduce ETc, and hence save water, while simultaneously minimizing or eliminating negative impacts of stress on fruit yield or quality. This approach differs from season-long stress in that the deficit irrigation is restricted to stress-tolerant periods. Essentially, there are two methods to achieve DI management of a crop, reducing the amount of water supplied or increasing the period between irrigation cycles.

Regarding reducing the quantity of water applied, Sustained DI (SDI) and Regulated DI (RDI) are the most widely used practices in several tree crops. SDI is when a reduced percentage of ETc is applied throughout the irrigation season without considering its phenological period or the accumulated water stress. Regulated deficit irrigation (RDI) is based on supplying some 100% of ETc when the crop is less tolerant to water stress and a reduced percentage for the rest of the season. The water stress tolerated by the crops is closely related to crop phenology and, therefore, a detailed knowledge on tree physiology is crucial for successful use of RDI. Deficit irrigation strategies are not recommended for young orchards, since conditions must be favoured under which trees reach maturity as soon as possible.

Concerning the methods based on increasing periods between irrigation events, Low frequency DI (LFDI) is when the soil is left to dry until the readily available water is consumed; then the soil is irrigated to field capacity and left to dry again. Under this strategy the crop is kept below a certain water stress threshold value (García-Tejero, 2010).

Options for enhancing irrigation efficiency in the agronomic category are related to crop management. Different strategies to improve rainfall use or reduce evaporation can be performed. In this respect, it is important to note that precipitation is not a reliable water source, but can contribute to some degree towards water needs. Therefore, usable rainfall or effective precipitation, which is the portion of total precipitation retained by soil available for plants, must be calculated in the water plant requirements.

The research reported here summarizes the results obtained in terms of the response of yield, fruit quality and nutritional tree status in citrus orchards under two irrigation systems, three deficit irrigation strategies and two effective precipitation values during five consecutive seasons (2006-2010). Also, the benefits of each irrigation strategy were estimated in terms of agricultural water productivity (WPagr).

3. Design factors

The different experimental plots were located in Puzol, Valencia (latitude 39º 34´ N; longitude 00º 24´ W, elevation 25 m) in the East of Spain, in commercial orchards of clementine cv. Nules mandarin adult trees (*Citrus clementine* Hort. Tanaka x *C. reticulata* Blanco) grafted onto citrange Carrizo rootstock [*C. sinensis* L. (Osb.) x *Poncirus trifoliata* L.(Raff.)], planted at a spacing of 3.5 m x 5.6 m (i.e. 510 trees ha^{-1}). This variety, grafted onto Carrizo citrange is highly representative in the study area, this being the most widely used rootstock in citrus orchards in the Comunidad Valenciana area (MARM, 2010).

3.1 Soil and water characteristics

The trees were grown on Cambic Arenosol soil (62.6% sand, 19.2% silt, 18.2% clay; pH 8.2; organic matter content 1.03% and a bulk density of 1.6 kg m^{-3}) with low water holding capacity (16%).

The irrigation water had an average electrical conductivity of 2.8 mS cm^{-1}, containing an annual average of 272, 212 and 100 mg L^{-1} of NO_3^-, Ca^{2+} and Mg^{2+}, respectively.

3.2 Climatic conditions

The general climatic conditions for the experimental sites is Mediterranean dry, with an average potential evapotranspiration (ET0) close to 1500 mm yr^{-1}, and annual rainfall between 250 and 500 mm yr^{-1}, with a high monthly variability distributed mainly from October to May. The thermal range is broad, with mild temperatures in winter, rarely below 0 ◦C and severe conditions in summer, with temperatures in many cases exceeding 40 ◦C. These environmental conditions promote an average annual water deficit of around 1000 mm.

3.3 Fertilization program

The nutrient-fertilizer rate and seasonal distribution for citrus plants was calculated for a 3.10 m canopy diameter in citrus trees grown under drip irrigation. Nitrogen (N) requirements were 400 g N $tree^{-1}$ $year^{-1}$ based on Legaz and Primo-Millo (1988), of which an average value of 58 and 49 % were supplied as potassium nitrate in 50 and 100 % canopy area coefficients of effective precipitation in UEP (use of effective precipitation) treatments, respectively. These coefficients were arbitrarily chosen. The N-remainder was provided by typical irrigation water in the Mediterranean area, with 272 ppm of nitrate concentration, as described above. The quantity of N contributed by the irrigation water was calculated using the formula described by Martinez et al., (2002). Phosphorus and potassium fertilizer demand was 120 g P_2O_5 tree-$year^{-1}$ applied as phosphoric acid (48% P_2O_5) and 475 g K_2O tree-$year^{-1}$ applied as potassium nitrate (44% K_2O equivalent). The basic iron needs per tree were distributed throughout the growing cycle in a similar way for N. Foliar spray treatments of zinc (Zn) and manganese (Mn) were applied as organic commercial fertilizer at 0.5% weight(w)/volume(v) (Zn: 6.6% w/w and Mn: 4.8% w/w) to correct deficiencies.

3.4 Irrigation scheduling

The amount of water applied to each tree was equivalent to the total seasonal crop evapotranspiration (ETc) calculated using the formula described by Aboukhaled et al. (1982).

$$\text{ETc}\,(\text{mm}) = \frac{\text{ETo}\,(\text{mm})}{\text{Kc}}$$

Where ETo is the reference crop evapo-transpiration under standard conditions and Kc is the crop coefficient (Table 1). This coefficient (Kc per month) accounts for crop-specific effects on overall crop water requirements and is a function of canopy size and leaf properties. The ETo values were determined using the Penman-Monteith approach (Allen et al. 1998) using hourly data collected by an automated weather station situated near the orchard The values obtained were 1108, 1041, 972, 1043 and 1092 mm yr^{-1} in 2006, 2007, 2008, 2009 and 2010 respectively. The Kc values were based on guidelines provided by Castel and Buj (1994). Irrigation water requirements were met by the effective rainfall (≥3 mm and ≤ 45 mm which resulted in soil water saturation) of the entire year plus irrigation water for the three years of the assay, respectively). The annual rainfall was 315, 516, 463, 472 and 392 mm yr^{-1} in 2006 to 2010, respectively.

There is scarcely any information about the use of rainfall by crops, possibly due to the difficulty of evaluation. In this research study, rainfall was recorded as the mean of three rain gauges placed in different parts of the orchard. Irrigation water requirements covered by effective precipitation (UPe) were calculated according to the following expression:

$$UPe\ (m^3\ tree^{-1}) = CA\ (m^2) \times Pe\ (L\ m^{-2}) \times F \times 0.001\ (L\ m^{-3})$$

Where CA is canopy area of the tree at the beginning of each growth cycle, Pe is effective precipitation corresponding to rainfall greater than 3 mm (lower values are not utilizable by the plant) and less than 33 mm (which saturate the soil profile and water percolates through soil to groundwater), F is the potential factor for effective precipitation use (0.5 or 1).

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Factor	0.97	0.96	0.97	0.91	0.81	0.91	1.00	1.16	1.09	1.24	1.07	0.93
Kc per month	0.505	0.500	0.505	0.474	0.422	0.474	0.521	0.604	0.567	0.646	0.557	0.484

Table 1. Month crop coefficient (Kc) = Factor x Kc mean (0.521)

Trees were surface and subsurface drip-irrigated, through eight pressure-compensating emitters (4 L h^{-1} each) per tree, placed every 88 cm in two drip lines, and at a depth of 30 cm in subsurface drip irrigated trees, both located within 100 cm of the tree trunk and producing a 33% wetted area (Keller and Karmelli, 1974). Moreover, plants were fertirrigated from 0 to 3 times per week, according to evapotranspiration demand and effective rainfall.

3.5 Experimental design

The assay treatments consisted of two irrigation systems, three regulated deficit irrigation practices and two effective precipitation coefficients. The combinations of these factors resulted in twelve treatments distributed in a randomised complete block design and with three replicates each, and fifty trees per plot (Table 2).

Irrigation treatments were subsurface drip irrigation (SDrI) and drip irrigation (DrI). Regulated deficit irrigation practices were:

i. Control fully irrigated trees where irrigation scheduling was based on the standard FAO approach replacing crop as described above. Therefore, 100 % of crop evapotranspiration (ETc) was covered during the whole year (100 % treatments)
ii. Standard regulated deficit irrigation (RDI_{70}) where water was applied at 70% of ETc during July (at the beginning of fruit growth) to the end of October (post-harvest). During the rest of the season water was applied at 100% of ETc.
iii. Alternate regulated deficit irrigation (RDI_{100-40}) where water was applied at 100-40 % alternate irrigation events of ETc during the same period explained above. Similarly, during the rest of the season water was applied at 100% of ETc.

To calculate the portion of total precipitation used by the plants (use of effective precipitation); two coefficients of effective precipitation (UEP) were arbitrarily employed, corresponding to 50 and 100 % % canopy area (% CA).

Treatments	Irrigation system[1]	ETc [%][2]	UPe [%CA][3]	Tree Treament^{-1}
DrI_{100-50}	DrI	100	50	54
$SDrI_{100-50}$	SDrI	100	50	51
DrI_{70-50}	DrI	100-70	50	51
$SDrI_{70-50}$	SDrI	100-70	50	54
$DrI_{100/40-50}$	DrI	100-100/40	50	54
$SDrI_{100/40-50}$	SDrI	100-100/40	50	51
$DrI_{100-100}$	DrI	100	100	51
$SDrI_{100-100}$	SDrI	100	100	54
DrI_{70-100}	DrI	100-70	100	54
$SDrI_{70-100}$	SDrI	100-70	100	51
$DrI_{100/40-1000}$	DrI	100-100/40	100	51
$SDrI_{100/40-100}$	SDrI	100-100/40	100	54

Table 2. Treatments performed during 2006-2009. [1]:Irrigation system, DrI: Drip irrigation, SDrI: Subsurface Drip irrigation; [2]:Regulated deficit irrigation, 100, 70 and 100-40 % of crop evapotranspiration (ETc). [3]:Use of effective precipitation

3.6 Sample collection and measurements

Spring-flush leaves from non-fruiting shoots (around 10 leaves per tree) were randomly sampled in November, from around the canopy. Then, leaves were frozen in liquid-N_2 and freeze-dried (lyophilised). Samples were ground with a water-refrigerated mill, then sieved through a 0.3 mm mesh sieve and stored at -20 ºC for further analysis, no more than one month later.

Macro and micronutrient concentration was measured to test nutritional status of the tree and quantify annual nutrient requirements of a crop. Total nitrogen content of spring flush leaves was determined using an Elemental Analyser (NC2500 Thermo Finnigan, Bremen, Germany). Other macronutrients were measured by simultaneous ICP emission spectrometry (iCAP-AES 6000, Thermo Scientific. Cambridge, United Kingdom). Results were expressed as a percentage of dry weight (DW).

In November of each year (19th, 17th and 22nd of November in the 1st, 2nd and 3rd year of the assay), which is the commercial harvest period, the yields of all replicates of each treatment were weighed and a representative sample of forty fruits per replication (5 fruits per tree from 8 trees per replication) was collected at random, weighed and internal fruit quality (including fruit weight, fruit diameter, peel thickness, peel and juice weight, total soluble-solids content, total acidity and colour index) was measured. The number of fruits was calculated using the ratio of yield to average weight of individual fruit. Fruit weight, peel and juice content were determined gravimetrically. Equatorial fruit diameter of samples was measured for each fruit using a digital calliper (Mitutoyo CD-15D, Japan) and the average value of the sample was calculated. Total soluble solids (TSS) content of juice (ºBrix) was measured using a digital refractometer (Atago PR-101 Alfa, Tokyo, Japan) and total acidity (TA) was assessed by titration with 0.1 N NaOH, using phenolphthalein as indicator. The ratio between TSS and TA, commonly called maturity index, was calculated. Colour index (CI) was measured taking three readings around the equatorial surface of each fruit using a Minolta Chroma Meter CR-300 (Minolta Camera Co. Ltd., Osaka, Japan). The results are given in the Hunter Lab Colour Scale. This system is based on *L*, *a* and *b* measurements. The *L* values represent light from zero (black) to 100 (white). The *a* values change from –*a* (greenness) to +*a* (redness), while the *b* value is from –b (blueness) to +b (yellowness). From *L*, *a* and *b* values, a ratio of 1000 ·a/L ·b is calculated to give the citrus colour index (Ladaniya, 2008).

In addition, impact of different irrigation scheduling on agricultural water productivity (WP) was evaluated, taking into account the water applied, through a ratio between the crop yield (kg), and the total water applied:

$$\text{WP}\left(\text{kg m}^{-3}\right) = \frac{\text{Yield}}{\text{irrigation + rain}}$$

3.7 Statistical analyses

Data are summarized in tables as means from three replicates ± standard errors. All data were statistically analysed using PROC ANOVA (SAS version 9, SAS Institute, Cary, NC, USA) and least significant difference multiple range-tests were used to identify differences among the means of the parameters examined. Significance was considered at $P < 0.05$.

4. Water saving irrigation response to water management strategies

The annual volumes of ETc covered by irrigation water and effective rainfall are shown in Table 3 for both irrigation systems (DrI and SdrI). The percentages of water irrigation savings due to the contribution of UPe and RDI strategies are also presented.

Regarding effective precipitation use percentage (50 or 100 % CA), the reduction in irrigation water applied was significantly higher when 100 % canopy area (an average over 36 %) was considered than for 50 % canopy area (20 %) in all the years tested. Moreover, significant differences between years were observed, with higher water saving in 2007, 2008 and 2009 (an average over 30 %) than in 2006 (20 %), due to increased rainfall volume during those years.

Concerning regulated deficit irrigation (RDI) strategies, the reduction of 100 to 70 (or 100-40 % ETc alternate irrigation event) in the percentage of ETc covered by irrigation water allowed a significant water irrigation saving of up to 16 %, without significant differences between deficit water management. In this parameter, significant differences among years were also recorded, with a lower irrigation saving in 2008 corresponding to the lower ETc. The coefficient used when calculating rainfall water use did not affect this variable.

The overall saving of irrigation water due to both UEP and RDI strategies maintained a similar trend to that described for the previous variable. The greatest savings were obtained using a coefficient of 100% CA with RDI management in 2007, achieving a 66 % reduction in the irrigation water supplied of ($DrI_{70\text{-}100}$ /$SDrI_{70\text{-}100}$ and $DrI_{100/40\text{-}100}$ /$SDrI_{100/40\text{-}100}$ treatments)

Year	Treatments	ETc covered by (m³ ha-year⁻¹)			Reduction in irrigation water by (%)		
		UPe	IW	UPe+IW	UEP	RDI	UEP + RDI
2006	DrI_{100-50}/ $SDrI_{100-50}$	853	4928	5781	14,76	0,00	14,76
	DrI_{70-50}/ $SDrI_{70-50}$	853	3903	4756	14,76	17,73	32,49
	$DrI_{100/40-50}$/$SDrI_{100/40-50}$	853	3898	4751	14,76	17,82	32,57
	$DrI_{100-100}$/ $SDrI_{100-100}$	1485	4256	5741	25,87	0,00	25,87
	DrI_{70-100} /$SDrI_{70-100}$	1485	3282	4767	25,87	16,97	42,83
	$DrI_{100/40-100}$ /$SDrI_{100/40-100}$	1485	3279	4764	25,87	17,02	42,88
2007	DrI_{100-50}/ $SDrI_{100-50}$	1230	4204	5434	22,64	0,00	22,64
	DrI_{70-50}/ $SDrI_{70-50}$	1230	3245	4475	22,64	17,65	40,28
	$DrI_{100/40-50}$/$SDrI_{100/40-50}$	1230	3219	4449	22,64	18,13	40,76
	$DrI_{100-100}$/ $SDrI_{100-100}$	2337	3011	5348	43,70	0,00	43,70
	DrI_{70-100} /$SDrI_{70-100}$	2337	1995	4332	43,70	19,00	62,70
	$DrI_{100/40-100}$ /$SDrI_{100/40-100}$	2337	2008	4345	43,70	18,75	62,45
2008	DrI_{100-50}/ $SDrI_{100-50}$	1141	3788	4929	23,15	0,00	23,15
	DrI_{70-50}/ $SDrI_{70-50}$	1141	3313	4454	23,15	9,64	32,79
	$DrI_{100/40-50}$/$SDrI_{100/40-50}$	1141	3332	4473	23,15	9,25	32,40
	$DrI_{100-100}$/ $SDrI_{100-100}$	2030	3244	5274	38,49	0,00	38,49
	DrI_{70-100} /$SDrI_{70-100}$	2030	2689	4719	38,49	10,52	49,01
	$DrI_{100/40-100}$ /$SDrI_{100/40-100}$	2030	2712	4742	38,49	10,09	48,58
2009	DrI_{100-50}/ $SDrI_{100-50}$	1136	4266	5402	21,03	0,00	21,03
	DrI_{70-50}/ $SDrI_{70-50}$	1136	3307	4443	21,03	17,75	38,78
	$DrI_{100/40-50}$/$SDrI_{100/40-50}$	1136	3292	4428	21,03	18,03	39,06
	$DrI_{100-100}$/ $SDrI_{100-100}$	2214	3350	5564	39,79	0,00	39,79
	DrI_{70-100} /$SDrI_{70-100}$	2214	2511	4725	39,79	15,08	54,87
	$DrI_{100/40-100}$ /$SDrI_{100/40-100}$	2214	2507	4721	39,79	15,15	54,94
2010	DrI_{100-50}/ $SDrI_{100-50}$	1072	4950	6022	17,80	0,00	17,80
	DrI_{70-50}/ $SDrI_{70-50}$	1072	3848	4920	17,80	18,30	36,10
	$DrI_{100/40-50}$/$SDrI_{100/40-50}$	1072	3849	4921	17,80	18,28	36,08
	$DrI_{100-100}$/ $SDrI_{100-100}$	2143	3836	5979	35,84	0,00	35,84
	DrI_{70-100} /$SDrI_{70-100}$	2143	2703	4846	35,84	18,95	54,79
	$DrI_{100/40-100}$ /$SDrI_{100/40-100}$	2143	2693	4836	35,84	19,12	54,96
ANOVA[5]	RDI[6]					***	***
	UEP[7]				***	NS	***
	Year				*	***	***
	RDI x UEP					NS	NS
	RDI x Year					NS	NS
	UEPxYear				NS	NS	NS

Table 3. Water irrigation saving response to different irrigation strategies. UPe: volume of rainfall water available to the root system. IW: irrigation water applied. [5]ANOVA: Significant effects of different irrigation strategies are given at P>0,05 (NS, not significant), P≤0,05 (*), P≤0,01 (**),P≤0,001 (***). [6]RDI: Regulated deficit irrigation (Control, 70 and 100-40 % ETc). [7]UEP: coefficient use in effective precipitation (50 and 100 % CA).

By using regulated deficit irrigation (RDI) strategies, savings in irrigation water were recorded in peach orchards without reducing yield (Mitchell and Chalmers, 1982). Citrus has also been studied under deficit irrigation strategies. Thus, deficit irrigation treatments compared with the control, drip irrigated by six pressure compensated emitters per tree, allowed seasonal water savings of between 12 and 18% (Velez et al., 2007). Similarly, experiments with RDI have been successful in citrus (Domingo et al. 1996; González-Altozano and Castel, 1999; Goldhamer and Salinas, 2000). Similar results were reported for almond (Goldhamer et al., 2000), apple (Ebel et al., 1995), apricot (Ruiz-Sánchez et al., 2000), pear (Mitchell et al., 1989), pistachio (Goldhamer and Beede, 2004), wine grape vines (Bravdo and Naor, 1996; McCarthy et al., 2002), and olive (Moriana et al., 2003; Fernández et al., 2006). Accordingly, Fereres and Soriano (2007) published a comprehensive review on the use of deficit irrigation techniques to reduce water use in agriculture. However, there is no available information on the different UEP factor effects on water irrigation savings.

5. Impact of water irrigation techniques on tree nutritional status

Regarding macronutrient and micronutrient concentration in the spring flush leaves, significant differences were observed resulting from seasonality in most of the nutrients analysed (Table 4). However, every year, values were within the range considered optimal according to the standards described by Emblenton et al. (1973) and Legaz and Primo-Millo (1988). Only, Mg concentration showed slightly higher values due to the high concentration of this element in the irrigation water.

Regarding different factor effects (IS, RDI and UEP), foliar concentrations did not differ significantly between treatments. However, several authors found a higher foliar concentration in trees under SDrI than that obtained in DrI (Chartzoulakis and Bertaki, 2001). This indicates that this irrigation system improved nutrient absorption.

6. Fruit yield and WP_{agr} response to irrigation strategies

Yield, expressed in kg, and fruit number per tree, fruit weight and others fruit quality parameters are shown in Tables 5 to 7. Season was observed to exert a significant effect on yield and fruit number parameters per tree (Table 1), with an evident alternate bearing pattern of trees during the assay, with years of low production and fruit number and high fruit weight ('off year') followed by years of high yield ('on year'). Similar results were also observed by other authors. Accordingly, El-Otmani et al. (2004) and Quiñones et al. (2011), among others, concluded that 'Nules' clementine mandarin is a cultivar with an alternate-bearing pattern and poor fruit-set with a large number of small-sized fruits during the 'on year' crop mainly.

According to the irrigation system, this factor significantly affected the yield, number of fruits per tree and percentage of fruits in the first category (> 78 mm). These variables were significantly lower under drip irrigation (DrI) than in subsurface irrigated trees (SDrI). In this regard, conflicting results have been found in the literature. A broad range of yield increases have been observed under SDrI when compared to surface, sprinkler, and even surface drip irrigation systems ranging from small to up to over 100% differences. Velez et al. (2007) in clementina de Nules mandarin subjected to different deficit irrigation observed, in two years of assay, that the deficit irrigation applied did not significantly reduce yield, nor average fruit weight compared with the control treatment. Besides there were no significant differences in fruit distribution by commercial sizes. The number of fruit harvested did not also vary between treatments, indicating that there were not carry over effects of the deficit irrigation applied. Research into SDrI has also been reported on crops including alfalfa (Oron et al., 1989; Bui and Osgood, 1990), asparagus (Sterret et al., 1990), cabbage and zucchini (Rubeiz et al., 1989), cantaloupe (Phene et al., 1987), cotton (Hutmacher et al., 1995) and tomatoes (Bogle et al., 1989), potatoes (Bisconer, 1987). Most yield increases have been attributed to better fertilization, better water management, improved water distribution uniformities, and improved disease and pest control. Grattan et al. (1988) cited better weed control as the major factor in the yield increases observed in their study. However, Yazar et al. (2002) obtained similar yield results for both irrigation methods in cotton. Brilay et al. (2003) also found a similar yield and fruit size in peach trees irrigated under drip and subsurface drip irrigation. In annual crops, like melon, surface drip irrigated plants yielded a higher percentage of 'first' category fruit along with greater equatorial diameter fruit compared to other treatments (Antunez et al. 2011).

Regarding deficit irrigation strategies, water stress significantly affected fruit weight and the percentage of fruit with a high calliper (up to 58 mm). Control trees with a 100 % ETc covered by irrigation water had significantly higher fruit weight and calliper than those irrigated under deficit regimes. Furthermore, these variables significantly increased with UEP when the latter rose from 50 to 100 % CA. In citrus, Ginestar and Castel (1996) also observed a decrease in production, although not significant, as the amount of irrigation water was reduced in Nules clementine. In almond, Goldhamer et al. (2006) analysed the impact of three different water stress timing patterns. The most successful stress timing pattern in terms of yield (considering fruit size and load) was the pattern that imposed sustained deficit irrigation by applying water at a given percentage of full ETc throughout the season. Furthermore, Romero et al. (2004) analysed the influence of several RDI strategies under subsurface and surface drip irrigation. Thus, RDI, with severe irrigation deprivation during kernel-filling (20% ETc) and a post-harvest recovery at 75% ETc or up to 50% ETc under subsurface drip irrigation, may be adequate in almonds under semiarid conditions, saving a significant amount of irrigation water. Deficit irrigation effects on yield and vegetative development have also been analysed for drip irrigated olives. Thus, some authors (Tognetti et al., 2006) determined that water availability might affect fruit weight before flowering or during the early stages of fruit growth rather than later in the summer season. Thus, irrigation of olive trees with drip systems from the beginning of pit hardening may be recommendable. Comparing different treatments, deficit irrigation during the whole summer resulted in improved plant water relations with respect to other watering regimes, while severe RDI differentiated treatments only slightly from rain fed plants (Tognetti et al., 2005).

A joint assessment of the effects of different irrigation strategies based exclusively on yield and water savings is difficult because crop response depends not only on irrigation, but also on climate, soil, cultivar, age, etc. In this sense, WP enables comparisons to be made incorporating all the data, thus establishing the most effective irrigation strategy (Garcia-Tejero et al., 2011).

In this assay, the different strategies significantly affected WP values. Regarding the irrigation system, SDrI resulted in significantly higher water efficiency than that obtained with DrI. This result could be due to the fact that subsurface drip systems may further

Year	Treatments	N	P	K	Ca	Mg	S	Na	B	Fe	Mn	Zn	Cu
2007	DrI_{100-50}	2.02	0.109	0.47	3.51	0.45	0.254	0.059	58.3	62.3	22.4	24.4	4.13
	$SDrI_{100-50}$	2.04	0.119	0.50	3.75	0.46	0.267	0.053	59.2	63.9	25.4	26.2	4.80
	DrI_{70-50}	2.02	0.106	0.48	3.28	0.42	0.236	0.048	53.7	48.1	22.4	25.2	4.57
	$SDrI_{70-50}$	2.02	0.112	0.44	3.23	0.44	0.251	0.051	53.6	50.3	21.6	23.6	4.53
	$DrI_{100/40-50}$	2.03	0.103	0.46	4.04	0.44	0.242	0.054	71.4	62.1	24.3	27.2	5.37
	$SDrI_{100/40-50}$	2.04	0.114	0.47	4.33	0.49	0.282	0.080	58.3	71.2	25.1	28.5	4.87
	$DrI_{100-100}$	2.00	0.096	0.43	3.48	0.40	0.218	0.044	60.3	59.5	23.3	26.2	5.27
	$SDrI_{100-100}$	2.02	0.106	0.49	3.67	0.44	0.250	0.049	63.0	61.7	24.3	28.1	5.43
	DrI_{70-100}	1.99	0.095	0.42	3.33	0.43	0.226	0.055	49.5	54.3	20.3	23.8	4.10
	$SDrI_{70-100}$	2.08	0.114	0.50	3.31	0.45	0.259	0.061	52.7	60.3	24.5	25.0	4.50
	$DrI_{100/40-100}$	1.99	0.091	0.41	2.80	0.41	0.215	0.058	48.7	43.6	22.3	23.8	3.87
	$SDrI_{100/40-100}$	2.08	0.104	0.46	3.57	0.41	0.237	0.045	56.5	56.2	23.1	23.2	4.33
2008	DrI_{100-50}	2.18	0.120	0.56	4.43	0.53	0.274	0.072	55.1	53.5	48.4	35.1	7.77
	$SDrI_{100-50}$	2.13	0.113	0.50	4.60	0.50	0.269	0.047	49.7	71.5	56.2	37.7	9.33
	DrI_{70-50}	2.18	0.124	0.58	4.64	0.54	0.286	0.080	57.8	59.7	58.3	40.1	8.13
	$SDrI_{70-50}$	2.15	0.113	0.53	4.38	0.48	0.256	0.059	57.7	75.3	52.7	36.9	9.50
	$DrI_{100/40-50}$	2.24	0.126	0.55	4.33	0.54	0.290	0.067	62.3	117.5	53.1	40.4	10.70
	$SDrI_{100/40-50}$	2.30	0.131	0.61	4.57	0.53	0.297	0.079	76.5	52.6	47.6	33.4	7.57
	$DrI_{100-100}$	2.32	0.134	0.64	4.46	0.52	0.298	0.070	47.3	49.0	45.2	29.8	6.43
	$SDrI_{100-100}$	2.37	0.129	0.55	4.43	0.53	0.292	0.061	99.2	90.1	53.0	39.1	8.77
	DrI_{70-100}	2.23	0.128	0.53	4.41	0.58	0.283	0.071	58.0	65.7	45.1	30.7	7.80
	$SDrI_{70-100}$	2.24	0.127	0.56	4.66	0.54	0.286	0.071	48.3	49.7	48.3	33.6	8.70
	$DrI_{100/40-100}$	2.23	0.130	0.61	4.56	0.56	0.299	0.085	41.7	24.1	40.6	30.9	7.17
	$SDrI_{100/40-100}$	2.22	0.130	0.62	4.53	0.59	0.294	0.071	55.8	41.2	40.6	27.4	10.43
2009	DrI_{100-50}	2.25	0.118	0.83	3.52	0.50	0.237	0.062	67.3	43.9	28.6	23.7	5.93
	$SDrI_{100-50}$	2.22	0.119	0.77	3.84	0.49	0.240	0.061	62.0	44.2	29.8	26.9	5.27
	DrI_{70-50}	2.23	0.106	0.73	3.36	0.47	0.211	0.059	52.3	48.3	27.6	24.9	5.50
	$SDrI_{70-50}$	2.25	0.107	0.74	3.36	0.45	0.214	0.050	52.9	38.9	27.2	24.5	5.87
	$DrI_{100/40-50}$	2.27	0.112	0.81	3.59	0.52	0.228	0.060	71.4	44.3	28.5	25.8	5.33
	$SDrI_{100/40-50}$	2.25	0.108	0.71	3.57	0.48	0.222	0.058	53.0	42.6	26.4	22.5	5.13
	$DrI_{100-100}$	2.25	0.116	0.75	3.58	0.50	0.244	0.056	58.4	37.0	29.6	26.2	5.43
	$SDrI_{100-100}$	2.28	0.109	0.70	3.54	0.46	0.237	0.053	69.1	47.4	32.8	32.2	6.10
	DrI_{70-100}	2.27	0.122	0.85	3.46	0.53	0.242	0.070	65.2	45.4	29.3	25.1	5.80
	$SDrI_{70-100}$	2.22	0.115	0.86	3.53	0.48	0.232	0.060	81.2	49.1	31.1	30.4	5.97
	$DrI_{100/40-100}$	2.20	0.112	0.86	3.31	0.48	0.211	0.067	59.1	40.3	30.1	29.1	6.03
	$SDrI_{100/40-100}$	2.27	0.114	0.75	3.49	0.48	0.235	0.058	60.2	41.8	30.6	27.1	6.77
2010	DrI_{100-50}	2.44	0.105	0.83	3.28	0.43	0.222	0.056	84.5	58.0	33.37	25.3	5.43
	$SDrI_{100-50}$	2.42	0.102	0.86	3.30	0.43	0.224	0.054	86.0	55.6	33.5	24.8	5.03
	DrI_{70-50}	2.40	0.102	0.96	3.39	0.45	0.214	0.052	58.7	58.9	32.7	30.4	5.63
	$SDrI_{70-50}$	2.41	0.108	1.04	3.43	0.45	0.234	0.055	67.4	53.5	31.8	27.5	5.33
	$DrI_{100/40-50}$	2.43	0.101	0.97	3.34	0.44	0.221	0.057	82.9	57.9	31.0	24.4	4.57
	$SDrI_{100/40-50}$	2.44	0.108	0.82	3.49	0.46	0.250	0.061	74.2	69.4	33.1	25.9	5.40
	$DrI_{100-100}$	2.40	0.112	1.08	3.64	0.47	0.236	0.062	72.3	73.9	33.8	32.5	5.60
	$SDrI_{100-100}$	2.43	0.105	0.83	3.37	0.45	0.229	0.048	69.4	67.9	32.0	29.7	5.80
	DrI_{70-100}	2.39	0.092	0.87	3.14	0.43	0.201	0.058	65.0	54.2	31.4	28.0	4.67
	$SDrI_{70-100}$	2.40	0.108	1.04	3.49	0.47	0.238	0.063	73.1	59.2	31.3	19.7	5.53
	$DrI_{100/40-100}$	2.42	0.096	0.91	3.22	0.45	0.208	0.059	66.9	58.4	32.9	24.5	5.40
	$SDrI_{100/40-100}$	2.44	0.102	0.96	3.28	0.45	0.224	0.057	54.5	56.9	31.6	24.7	5.43

ANOVA[1]	IS[2]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	RDI[3]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	UEP[4]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	Year	***	***	***	***	***	NS	***	**	***	***	***	***
	IS x RDI	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	IS x UEP	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	IS x Year	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	RDI x UEP	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	RDI x Year	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	UEP x Year	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 4. Effect of irrigation strategies on macronutrient concentration (% dry weight) and micronutrient (ppm) concentration. [1]ANOVA: Significant effects of different irrigation strategies are given at $P>0,05$ (NS, not significant), $P\leq0,05$ (*), $P\leq0,01$ (**),$P\leq0,001$ (***). [2]IS: irrigation system (SDrI and DrI); [3]RDI: Regulated deficit irrigation (Control, 70 and 100-40 % ETc). [4]UEP: coefficient use in effective precipitation (50 and 100 % CA).

improve irrigation and fertilizer use efficiency because water and nutrients are applied directly to the root zone (Camp, 1998). Boss (1985) also obtained less WP in drip irrigated trees (microjets) than trees irrigated by subsurface drip. However, Bryla et al. (2003) did not observe significant differences in this variable between peach trees irrigated by surface and subsurface drip.

Concerning the effect of deficit irrigation, water use significantly increased by increasing water stress. García-Tejero et al. (2011) affirmed that WP was strongly influenced by the irrigation strategy employed at different phenological stages, rather than the amount of water in orange trees subjected to different deficit irrigation regimes. In this sense, the best results were registered when stress was applied at fruit maturity. However, the most restrictive treatment during fruit growth had a descending WP, registering values below even the fully irrigated treatment. Treatments in which water stress was applied at flowering and maturity showed similar WP values. Clearly, WP depends not only on the total water applied but also on when it is applied. Dissimilar results were found by Ibrahim and Abd El-Samad (2009) for pomegranate trees irrigated at 70%, 50% and 30% of available soil water. WP diminishing in trees with high deficit irrigation regimes (46-52 % and 2-6% of tree water needs).

The factor used to calculate the volume of rainwater available to the root system also affected the WP variable. Thus, efficiency values were higher in trees that theoretically used 100% of CA than in those that used 50 %. As indicated, there is no information available on the different UEP factor effects on water irrigation savings.

7. Effect of irrigation management on fruit quality parameters

With regard to fruit quality (Table 7), the studied factors and their interactions did not significantly affect peel thickness, or the percentage of pulp or juice. Only UEP significantly affected juice percentage with higher values in 50 % CA irrigated trees. This result could be due to the high volume of water applied in these plants. In other studies on grapefruit (Cruse et al., 1982), orange (Castel and Buj, 1990), Satsuma mandarin (Salustiano, Rabe and Peng, 1998) and Nules mandarin (Velez et al., 2007) significant differences due to differential irrigation doses were not found for these parameters either.

Year	Treatments	Yield (kg tree^{-1})	Fruit weight (g)	Nº fruit tree^{-1}	WP (kg m^{-3})
2007	DrI_{100-50}	62.5	107.1	597	6.45
	$SDrI_{100-50}$	66.6	110.8	610	6.90
	DrI_{70-50}	68.3	107.6	651	6.95
	$SDrI_{70-50}$	74.0	110.2	679	7.55
	$DrI_{100/40-50}$	72.3	106.1	700	9.10
	$SDrI_{100/40-50}$	73.0	112.3	662	9.20
	$DrI_{100-100}$	69.4	109.4	647	8.50
	$SDrI_{100-100}$	76.3	110.7	701	9.35
	DrI_{70-100}	59.3	99.7	596	7.50
	$SDrI_{70-100}$	73.8	105.1	707	9.30
	$DrI_{100/40-100}$	66.0	107.3	616	8.10
	$SDrI_{100/40-100}$	74.2	108.8	686	9.15
2008	DrI_{100-50}	26.0	103.2	252	4.09
	$SDrI_{100-50}$	38.7	94.1	411	6.44
	DrI_{70-50}	39.7	88.5	450	7.13
	$SDrI_{70-50}$	38.2	97.3	392	6.87
	$DrI_{100/40-50}$	28.6	92.6	306	5.10
	$SDrI_{100/40-50}$	37.6	89.6	426	6.72
	$DrI_{100-100}$	39.1	107.1	365	7.18
	$SDrI_{100-100}$	41.1	100.7	418	7.53
	DrI_{70-100}	41.8	94.9	422	9.24
	$SDrI_{70-100}$	45.6	102.4	445	10.10
	$DrI_{100/40-100}$	35.2	95.3	364	7.72
	$SDrI_{100/40-100}$	47.4	97.0	486	10.39
2009	DrI_{100-50}	39.7	112.6	353	4.63
	$SDrI_{100-50}$	48.4	110.4	442	5.64
	DrI_{70-50}	48.6	99.2	484	6.78
	$SDrI_{70-50}$	50.0	94.7	528	6.98
	$DrI_{100/40-50}$	33.0	95.1	350	4.63
	$SDrI_{100/40-50}$	42.4	100.4	422	5.95
	$DrI_{100-100}$	44.5	111.0	402	4.94
	$SDrI_{100-100}$	53.0	103.7	521	5.89
	DrI_{70-100}	35.9	107.4	334	4.84
	$SDrI_{70-100}$	47.9	104.9	482	6.46
	$DrI_{100/40-100}$	30.0	101.5	296	4.05
	$SDrI_{100/40-100}$	46.3	105.7	439	6.26
2010	DrI_{100-50}	31.1	96.0	324	3.8
	$SDrI_{100-50}$	32.8	95.9	343	4.0
	DrI_{70-50}	31.9	92.0	347	4.9
	$SDrI_{70-50}$	28.8	89.6	326	4.5
	$DrI_{100/40-50}$	28.8	693.5	314	4.5
	$SDrI_{100/40-50}$	26.1	91.8	289	4.1
	$DrI_{100-100}$	30.9	102.9	300	4.8
	$SDrI_{100-100}$	35.5	95.9	372	5.5
	DrI_{70-100}	21.8	103.1	210	4.8
	$SDrI_{70-100}$	33.4	100.2	335	7.4
	$DrI_{100/40-100}$	21.8	93.9	234	4.8
	$SDrI_{100/40-100}$	34.3	94.2	361	7.6

ANOVA[1]	IS[2]	***	NS	***	***
	RDI[3]	NS	*	NS	*
	UEP[4]	NS	*	NS	***
	Year	***	***	***	***
	IS x RDI	NS	NS	NS	NS
	IS x UEP	NS	NS	NS	NS
	IS x Year	NS	NS	NS	NS
	RDI x UEP	NS	NS	NS	NS
	RDI x Year	NS	NS	NS	NS
	UEP x Year	NS	NS	NS	NS

Table 5. Effect of irrigation strategies on yield and fruit parameters and water use efficiency. [1]ANOVA: Significant effects of different irrigation strategies are given at P>0,05 (NS, not significant), P≤0,05 (*), P≤0,01 (**),P≤0,001 (***). [2]IS: irrigation system (SDrI and DrI); [3]RDI: Regulated deficit irrigation (Control, 70 and 100-40 % ETc). [4]UEP: coefficient use in effective precipitation (50 and 100 % CA).

As for the other quality parameters analysed, both IS and RDI and their interaction significantly affected total acidity (TA), total soluble solids (TSS) and maturity index (IM). In drip irrigated trees, control trees showed higher TA and IM than that recorded for the juice of fruits from deficit irrigated plants (70 or alternate irrigation events 40-100 % ETc). However, under subsurface drip irrigation an opposite trend was observed. Regarding TSS, higher values were recorded in drip irrigated trees and under water stress conditions. Similarly to what occurs in SDrI, Ginestar and Castel (1996) only detected an increase (albeit insignificant) in acidity on decreasing water doses in drip irrigated trees of Nules clementine. Other researchers (Cruse et al., 1982; Koo and Smajstrla, 1985, Castel and Buj, 1990; Eliades, 1994, Peng and Rabe, 1998) described a similar pattern to that described in this assay. Velez et al. (2007) observed that fruit quality parameters were slightly altered by the deficit irrigation applied. Thus, fruit from the deficit irrigated trees was more acidic and was not sweeter than that from the control trees in the first year of the assay, but fruit from water stress trees had significantly higher Brix and similar acidity in the second year. On the other hand, in both years, the MI was not significantly altered by the water restrictions applied. Pérez-Sarmiento et al. (2010) also found that TSS values were increased significantly by RDI treatment, whereas TA was equal in control and deficit treatments, and therefore the TSS/TA ratio increased significantly in the RDI treatment. Thus, fruits from RDI treatment can be considered of high quality since TSS increased without affecting acidity (Scandella et al., 1997).

RDI has been used successfully, maintaining yield and fruit quality, including higher values of total soluble solids, tritratable acidity in many fruit species (Ebel et al., 1995; López et al., 2008), citrus species (Sánchez-Blanco et al., 1989; Castel and Buj, 1990; Domingo et al., 1996; González-Altozano and Castel, 1999; Goldhamer and Salinas, 2000), apricot trees (Ruiz-Sanchez et al., 2000), nut species (Romero et al., 2004), wine grape vines (Bravdo and Naor, 1996; McCarthy et al., 2002) and olives (Moriana et al., 2003).

The analysis of fruit peel colour (CI) showed that only IS affected this variable, with greener fruit corresponding to the DrI treatments than those obtained for SDrI. An opposite pattern was obtained in apricot fruit indices (Pérez-Sarmiento et al., 2010). Fruits from RDI treated trees showed higher CI values. The increase in this parameter in apricot fruits from RDI plants can be associated to a reduction in carotenoid accumulation, attributed to oxidation

Year	Treatments	Calliper	> 78 mm	78-67	67-58	58-50	< 50
2007	DrI_{100-50}	62.5	0.3	14.41	43.9	36.7	4,7
	$SDrI_{100-50}$	66.6	0.0	9.5	41.7	44.3	4,5
	DrI_{70-50}	68.3	0.0	3.8	40.3	45.3	10,6
	$SDrI_{70-50}$	74.0	0.0	5.1	47.3	41.6	6,0
	$DrI_{100/40-50}$	72.3	0.0	11.7	46.7	38.0	3,6
	$SDrI_{100/40-50}$	73.0	0.3	8.7	50.0	35.5	5,5
	$DrI_{100-100}$	69.4	0.3	11.4	50.5	35.3	2,5
	$SDrI_{100-100}$	76.3	0.0	9.7	55.5	29.6	5,2
	DrI_{70-100}	59.3	0.0	9.0	49.8	35.1	6,1
	$SDrI_{70-100}$	73.8	0.6	12.0	52.5	30.2	4,7
	$DrI_{100/40-100}$	66.0	0.0	11.7	53.0	31.7	3,6
	$SDrI_{100/40-100}$	74.2	0.6	7.2	53.4	35.9	2,9
2008	DrI_{100-50}	61.9	0.0	18.9	64.6	16.1	0,4
	$SDrI_{100-50}$	61.8	0.5	15.6	66.5	17.1	0,3
	DrI_{70-50}	59.7	0.0	9.0	63.6	26.1	1,3
	$SDrI_{70-50}$	60.9	0.0	15.3	66.7	17.1	0,9
	$DrI_{100/40-50}$	60.7	0.0	14.2	61.7	23.8	0,3
	$SDrI_{100/40-50}$	60.7	0.0	22.1	56.2	21.4	0,3
	$DrI_{100-100}$	62.7	0.0	25.2	61.1	13.4	0,3
	$SDrI_{100-100}$	62.1	0.9	23.6	56.6	15.2	3,7
	DrI_{70-100}	60.9	0.5	15.6	62.7	20.3	0,9
	$SDrI_{70-100}$	62.3	0.0	24.0	62.0	13.0	1,0
	$DrI_{100/40-100}$	60.4	0.0	13.7	60.3	25.2	0,8
	$SDrI_{100/40-100}$	61.2	0.0	14.4	65.4	19.9	0,3
2009	DrI_{100-50}	59.8	0.6	20.6	47.2	29.2	2,4
	$SDrI_{100-50}$	58.8	0.0	14.1	46.2	36.9	2,8
	DrI_{70-50}	57.1	0.0	6.4	47.1	39.7	6,8
	$SDrI_{70-50}$	58.3	0.0	7.8	54.1	34.5	3,6
	$DrI_{100/40-50}$	59.4	0.0	18.2	50.0	29.6	2,2
	$SDrI_{100/40-50}$	59.4	0.6	12.8	54.5	28.7	3,4
	$DrI_{100-100}$	60.0	0.0	17.1	50.0	27.4	5,5
	$SDrI_{100-100}$	59.8	0.0	14.8	59.4	23.0	2,8
	DrI_{70-100}	59.2	0.0	12.2	54.9	29.0	3,9
	$SDrI_{70-100}$	60.5	1.1	17.0	55.6	24.2	2,1
	$DrI_{100/40-100}$	60.2	0.0	17.2	56.7	24.1	2,0
	$SDrI_{100/40-100}$	59.6	1.1	10.9	57.4	28.7	1,9
2010	DrI_{100-50}	59.2	0.0	8.1	47.1	39.3	5,5
	$SDrI_{100-50}$	59.0	0.6	6.3	47.96	43.9	1,2
	DrI_{70-50}	58.3	0.0	3.8	46.8	46.2	3,2
	$SDrI_{70-50}$	59.7	0.3	10.8	46.7	40.8	1,4
	$DrI_{100/40-50}$	58.9	0.0	6.8	49.5	40.1	3,6
	$SDrI_{100/40-50}$	58.4	0.0	4.2	44.1	49.8	1,9
	$DrI_{100-100}$	60.4	0.0	10.5	57.0	31.4	1,1
	$SDrI_{100-100}$	59.9	0.0	9.0	51.4	37.6	2,0
	DrI_{70-100}	60.1	0.0	9.6	54.1	33.6	2,7
	$SDrI_{70-100}$	59.9	0.0	7.4	54.4	36.6	1,6
	$DrI_{100/40-100}$	59.7	0.0	11.3	47.8	37.4	3,5
	$SDrI_{100/40-100}$	59.2	0.3	8.6	49.3	38.5	3,3

ANOVA[1]	IS[2]	NS	*	NS	NS	NS	NS
	RDI[3]	*	NS	**	NS	NS	NS
	UEP[4]	**	NS	*	***	***	NS
	Year	***	NS	***	***	***	***
	IS x RDI	NS	NS	NS	NS	NS	NS
	IS x UEP	NS	NS	NS	NS	NS	NS
	IS x Year	NS	NS	NS	NS	NS	NS
	RDRI x UEP	NS	NS	NS	NS	NS	NS
	RDRI x Year	NS	NS	NS	NS	NS	NS
	UEP x Year	NS	NS	NS	NS	NS	NS

Table 6. Effect of irrigation strategies on fruit calliper and percentage of fruit in each commercial calliper. [1]ANOVA: Significant effects of different irrigation strategies are given at P>0,05 (NS, not significant), P≤0,05 (*), P≤0,01 (**),P≤0,001 (***). [2]IS: irrigation system (SDrI and DrI); [3]RDI: Regulated deficit irrigation (Control, 70 and 100-40 % ETc). [4]UEP: coefficient use in effective precipitation (50 and 100 % CA).

Year	Treatments	Peel thickness	% Peel	% Juice	TA[5] (º Brix)	TSS[6]	IM[7]	CI[8]
2007	DrI_{100-50}	2.95	52.4	47.6	0.88	13.2	15,0	8.8
	$SDrI_{100-50}$	2.85	51.7	48.3	0.89	12.9	14,5	8.5
	DrI_{70-50}	3.85	50.8	49.2	0.94	13.1	13,9	8.0
	$SDrI_{70-50}$	3.40	50.9	49.1	0.91	13.1	14,4	8.3
	$DrI_{100/40-50}$	3.00	51.6	48.4	0.89	13.2	14,8	8.3
	$SDrI_{100/40-50}$	2.85	50.4	49.6	0.89	12.9	14,5	9.4
	$DrI_{100-100}$	2.95	52.4	47.6	0.97	13.3	13,7	9.1
	$SDrI_{100-100}$	2.90	51.4	48.6	0.92	13.2	14,3	8.5
	DrI_{70-100}	2.75	50.7	49.3	1.04	14.1	13,6	9.0
	$SDrI_{70-100}$	2.80	50.8	49.2	0.91	13.3	14,6	9.8
	$DrI_{100/40-100}$	2.90	52.0	48	0.99	13.8	13,9	8.9
	$SDrI_{100/40-100}$	2.85	51.4	48.6	0.91	13.5	14,8	9.4
2008	DrI_{100-50}	3.50	49.1	50.9	0.90	13.6	15,1	9.6
	$SDrI_{100-50}$	3.37	49.1	50.9	0.97	13.2	13,6	9.3
	DrI_{70-50}	3.37	48.8	51.2	0.90	14.0	15,6	9.6
	$SDrI_{70-50}$	3.47	50.9	49.1	0.87	13.4	15,4	9.4
	$DrI_{100/40-50}$	3.57	51.5	48.5	0.93	14.1	15,2	8.5
	$SDrI_{100/40-50}$	3.43	48.7	51.3	0.93	13.9	14,9	9.3
	$DrI_{100-100}$	3.40	49.4	50.6	0.87	12.6	14,5	8.3
	$SDrI_{100-100}$	3.40	49.7	50.3	0.87	12.7	14,6	9.1
	DrI_{70-100}	3.43	49.5	50.5	0.93	13.1	14,1	9.2
	$SDrI_{70-100}$	3.53	50.0	50	0.90	13.2	14,7	11.0
	$DrI_{100/40-100}$	3.43	49.7	50.3	1.00	13.7	13,7	9.8
	$SDrI_{100/40-100}$	3.37	48.6	51.4	0.80	13.2	16,5	9.2
2009	DrI_{100-50}	3.29	51.9	48.1	1.02	12.7	12,5	7.8
	$SDrI_{100-50}$	3.15	51.7	48.3	1.00	124	12,4	10.4
	DrI_{70-50}	3.21	50.9	49.1	1.02	13.1	12,8	7.9
	$SDrI_{70-50}$	3.04	50.0	50	1.04	12.6	12,1	8.0
	$DrI_{100/40-50}$	3.04	51.2	48.8	1.15	13.0	11,3	6.8
	$SDrI_{100/40-50}$	3.24	51.6	48.4	1.09	12.8	11,7	6.4
	$DrI_{100-100}$	3.20	53.2	46.8	1.04	12.7	12,2	7.0
	$SDrI_{100-100}$	2.98	51.4	48.6	1.11	12.7	11,4	6.8

	DrI$_{70\text{-}100}$	3.27	53.0	47	1.10	12.6	11,5	7.8
	SDrI$_{70\text{-}100}$	3.18	51.8	48.2	1.02	12.6	12,4	9.0
	DrI$_{100/40\text{-}100}$	3.12	52.9	47.1	1.13	12.6	11,2	7.0
	SDrI$_{100/40\text{-}100}$	3.01	52.0	48	0.96	12.9	13,4	9.5
2010	DrI$_{100\text{-}50}$	2.84	49.6	50.4	1.16	12.9	11,1	
	SDrI$_{100\text{-}50}$	2.94	52.0	48	1.16	13.0	11,2	
	DrI$_{70\text{-}50}$	2.93	51.9	48.1	1.33	14.2	10,7	
	SDrI$_{70\text{-}50}$	2.75	50.9	49.1	1.16	13.0	11,2	
	DrI$_{100/40\text{-}50}$	3.00	51.0	49	1.33	14.0	10,5	
	SDrI$_{100/40\text{-}50}$	2.93	51.3	48.7	1.15	13.0	11,3	
	DrI$_{100\text{-}100}$	2.93	48.3	51.7	1.19	13.0	10,9	
	SDrI$_{100\text{-}100}$	2.76	52.3	47.7	1.18	13.1	11,1	
	DrI$_{70\text{-}100}$	3.12	52.1	47.9	1.28	13.6	10,6	
	SDrI$_{70\text{-}100}$	3.07	54.8	45.2	1.20	13.5	11,3	
	DrI$_{100/40\text{-}100}$	3.18	53.1	46.9	1.29	14.0	10,9	
	SDrI$_{100/40\text{-}100}$	2.94	53.7	46.3	1.23	13.5	11,0	
ANOVA[1]	IS[2]	NS	NS	NS	***	***	*	*
	RDI[3]	NS	NS	NS	NS	***	NS	NS
	UEP[4]	NS	NS	*	NS	NS	NS	NS
	Year	***	***	***	***	***	***	***
	IS x RDI	NS	NS	NS	**	NS	**	NS
	IS x UEP	NS	NS	NS	NS	NS	NS	NS
	IS x Year	NS	NS	NS	NS	NS	NS	NS
	RDRI x UEP	NS	NS	NS	NS	NS	NS	NS
	RDRI x Year	NS	NS	NS	NS	NS	NS	NS
	UEP x Year	NS	NS	NS	NS	NS	NS	NS

Table 7. Effect of irrigation strategies on fruit quality parameters. [1]ANOVA: Significant effects of different irrigation strategies are given at P>0,05 (NS, not significant), P≤0,05 (*), P≤0,01 (**),P≤0,001 (***). [2]IS: irrigation system (SDrI and DrI); [3]RDI: Regulated deficit irrigation (Control, 70 and 100-40 % ETc). [4]UEP: coefficient use in effective precipitation (50 and 100 % CA).. [4]UEP: coefficient use in effective precipitation (50 and 100 % CA). [5]TA: total acidity. [6]TSS: total soluble solids. [7]MI: maturity index, ratio between TSS/TA. [8]CI: colour index.

by exposure to light (Ruiz et al., 2005). This exposure to light in fruits from the RDI treatment is related to a significant reduction in the vegetative growth of the trees during fruit development, implying a high exposure of fruits to the light. Similar trends were observed in peach fruits under RDI (Gelly et al., 2003; Buendía et al., 2008).

Significant differences were observed resulting from seasonality in all the fruit quality variables analysed (Table 7). However, values were within the range considered optimal according to the standards established by González-Sicilia (1968).

8. Conclusions and future research

Efficient irrigation systems management at the farm level appears to be a very important factor in irrigated agriculture and, given the competition for water resources with other sectors, is a key issue in terms of the economic and environmental sustainability of agriculture. In general, surface and pressurized irrigation systems can attain a reasonable level of efficiency, when they are well designed, adequately operated and appropriately selected for specific conditions.

Subsurface drip irrigated leads to higher fruit production and water use efficiency and regulated deficit irrigation also provides savings in irrigation water without reducing yield. Thus, both subsurface drip systems and water stress at certain phenological stages of the crop have been demonstrated as a useful tool to improve irrigation management and maintain sustainable production levels at the field scale under arid and semi-arid conditions. Moreover, highly stressful deficit irrigation should not be applied during flowering or fruit-growth periods, in order to ensure yield.

In addition, it is important to emphasize the importance on the use of effective rainfall in reducing the volumes of water applied, without affecting either production or fruit quality.

Other potential strategies for future use, such as partial root-zone, drying by irrigating half of the root-zone while the other half is kept under dry soil, alternating irrigation from one half to the other every 2-3 weeks, low-frequency deficit irrigation, or higher water stress all appear to be promising techniques. Further research is needed to analyse the effects of these strategies on yield, nutritional status, fruit quality and water irrigation savings.

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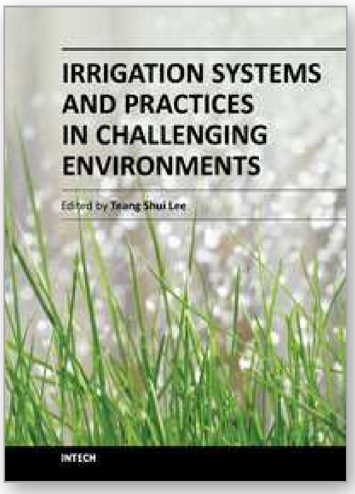

Irrigation Systems and Practices in Challenging Environments

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The book Irrigation Systems and Practices in Challenging Environments is divided into two interesting sections, with the first section titled Agricultural Water Productivity in Stressed Environments, which consists of nine chapters technically crafted by experts in their own right in their fields of expertise. Topics range from effects of irrigation on the physiology of plants, deficit irrigation practices and the genetic manipulation, to creating drought tolerant variety and a host of interesting topics to cater for the those interested in the plant water soil atmosphere relationships and agronomic practices relevant in many challenging environments, more so with the onslaught of global warming, climate change and the accompanying agro-meteorological impacts. The second section, with eight chapters, deals with systems of irrigation practices around the world, covering different climate zones apart from showing casing practices for sustainable irrigation practices and more efficient ways of conveying irrigation waters - the life blood of agriculture, undoubtedly the most important sector in the world.