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Irrigation Factor Approach Based on Soil Water Content: A Nectarine Orchard Case Study

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Abstract: Precision agriculture requires irrigation supported by an accurate knowledge of the crop water requirements. In this paper, a novel approach for drip irrigation scheduling of fruit trees is presented based on the results obtained during a full growing season in an early-maturing nectarine orchard growing in a clay loam soil in a Mediterranean environment. Real-time water content was monitored in the soil profile of the main root exploration zone by means of capacitance probes; in addition, plant water status (midday stem water potential and leaf gas exchange) and canopy development were frequently measured throughout the vegetative cycle. The reference evapotranspiration (ET_0) values, taken from a nearby automatic meteorological station, and the measured irrigation values allowed the determination of the irrigation factors once irrigation drainage during the season was assumed to be negligible and plant water status was proved to be adequate. The proposed irrigation factors offer a hands-on approach as an easy tool for irrigation management based on suitable soil water deficits, allowing the water requirements of nectarine trees under precision irrigation to be determined in semi-arid agrosystems where water resources are limited.

Keywords: automated irrigation; irrigation factor; Mediterranean conditions; *Prunus persica* sp.; reference evapotranspiration (ET_0); soil water content

1. Introduction

Agriculture is the largest freshwater consuming sector in Mediterranean areas, characterized by water shortages that will inevitably be aggravated by climate change, population growth, and land use change due to agricultural expansion, deforestation, and competition between urban, tourism, and industrial activities. This situation demands methodologies and innovative tools that will permit adequate decision-making with the objective of increasing the efficiency of agricultural production and enhancing useful freshwater resources.

The first step was to establish irrigation systems from full soil cover irrigation (flood, furrow) to pressurized systems with the development of hydraulic control valves [1]. Drip irrigation has emerged as one of the most important innovations in agriculture since the 1960s because it allows the optimal use of both water and fertilizers [2,3]. A further step forward consisted of bringing drip irrigation into line with the precision agriculture concept, according to which an accurate knowledge of the crop water requirements is required for precise irrigation scheduling [4].

The most commonly used method for estimating crop water requirements follows the standardized FAO-56 Penman–Monteith approach that estimates crop evapotranspiration (ET_c) as the product of the reference evapotranspiration (ET_0) and a specific crop coefficient (K_c). ET_0 is first estimated on the basis of site meteorological variables and is defined as the water consumed by an extensive surface of green, well-watered grass of uniform height, actively growing, and completely shading the ground, whereas K_c is applied to take into account the crop species, development stages, and environmental factors [5]. The frequency of irrigation events as well as the percentage of wetted soil area influence ET_c and, thus, need to be taken into account when determining K_c. This is better done by splitting K_c into two separate coefficients, one for crop transpiration, known as the basal crop coefficient (K_{cb}), and one for soil evaporation (K_e). More particularly, K_{cb} is the ratio of ET_c to ET_0 when the soil surface is dry but transpiration is occurring at a potential rate, that is, soil water is not limiting transpiration [5]. Therefore, the crop water needs for a certain period of time are given by: ET_c (mm) = $ET_0 \times (K_{cb} + K_e)$.

Daily ET_0 values are available through agro-meteorological stations and irrigation advisory centers worldwide [6]. The success of the FAO-56 Penman–Monteith's approach is due primarily to the simplicity and yet relatively high level of robustness of the procedures as well as its transferability [7]. However, Ramirez-Cuesta et al. [8] reported that accurate ET_0 assessment at the regional scale is complicated by the limited number of weather stations and the strict requirements concerning their location and surrounding physical conditions for the collection of valid meteorological data. Furthermore, the diversity of parameters affecting the K_c coefficient must be taken into account [9]. This involves the use of expensive, large weighing or drainage lysimeters [10–12] that measure the variables (irrigation, precipitation, drainage, runoff, and variation of the water content in the soil profile) involved in the process for determining K_c values. Some authors combined the dual coefficient approach and remote sensing imagery to assess crop water demands [13].

Recent studies have demonstrated that precise irrigation can be achieved based on plant water status because plants integrate both soil-atmosphere conditions and the crop phenological stage [14–16]. Some of the plant-based indicators for irrigation scheduling are the stem water potential (Ψ_{stem}) [17] and the indices derived from trunk diameter fluctuations [18]. Reference baselines calculated as the relationship between these plant water status indicators and meteorological variables (e.g., air temperature and deficit vapor pressure) in non-limiting soil water conditions have been proposed for irrigation scheduling in many fruit crops [19–22]. However, the equipment used to obtain the above indicators needs a significant input of labor to properly monitor the plant water status as well as specialized staff for processing data.

For these reasons, soil characteristics and root exploration, along with the soil water content, have become a major objective for the precision irrigation scheduling of fruit crops [23–25]. Therefore, knowing the amount of water in the soil at any given time has become the main factor in effective irrigation scheduling.

Sensor technologies for measuring soil moisture include neutron probes, frequency domain reflectometry (FDR or capacitance probe), time domain reflectometry (TDR), electrical resistivity measurements, heat pulse sensors, and fiber optic sensors delivering soil water content (SWC) values [23–28]. These sensors have been developed and made commercially available for water management applications because they are able to detect irrigation events, providing the corresponding output as an electrical signal that needs to be calibrated previously [29,30].

Early-maturing cultivars of *Prunus persica* L. are associated with lower water needs [31]. This, along with the limited availability of water for agriculture and improved market opportunities may explain the rise in interest for new varieties of early-maturing fruit trees in Southern Spain in recent years.

This paper describes a methodology to obtain a dimensionless irrigation factor (IF) that serves as a simple, practical, and precise drip irrigation method for early-maturing nectarine trees cultivated in a Mediterranean climate under non-limited soil water conditions. Information derived from capacitance probes for the real-time monitoring of the soil water content (SWC) and agro-meteorological variables as well as the plant water status (stem water potential and gas exchange) and canopy cover measurements were assessed.

2. Materials and Methods

2.1. Experimental Site and Plant Material

The study was performed in 2015 in a 0.5 ha orchard of five-year-old extra-early maturing nectarine trees (*Prunus persica* L. Batsch, cv. Flariba, on GxN-15 rootstock), at the CEBAS-CSIC experimental station in Santomera, Murcia, Spain (38°06′31′′ N, 1°02′14′′ W, 110 m altitude). Trees were spaced at 6.5 m × 3.5 m and trained to an open-center canopy. The soil in the 0–50 cm layer was highly calcareous (45% calcium carbonate), with a clay loam texture (clay fraction: 41% illite, 17% smectite, and 30% palygorskite), low organic matter content (1.3%), and a cationic exchange capacity of 97.9 mmol kg^{-1}. The average bulk density was 1.43 g cm^{-3}. The soil water content at field capacity and permanent wilting point were 0.29 and 0.14 m^3 m^{-3}, respectively (Table 1).

Table 1. Physico-chemical soil analysis of the experimental plot.

Physical Parameters	
Sand (%)	30.7
Silt (%)	38.0
Clay (%)	31.3
Soil texture	Clay-Loam
Bulk density (g cm^{-3})	1.43
Field Capacity (m^3 m^{-3})	0.29
Wilting Point (m^3 m^{-3})	0.14
Saturation (m^3 m^{-3})	0.50
Chemical Parameters	
$CE_{1:5}$ (dS m^{-1})	0.47
pH	7.59
CEC* (mmol kg^{-1})	97.90
Organic matter (%)	1.36
$CaCO_3$ total (%)	44.81
$CaCO_3$ active (%)	13.81
$P_{available}$ (mmol kg^{-1})	0.95
$K_{available}$ (mmol kg^{-1})	6.07
$Na_{1:5}$ (mmol kg^{-1})	4.17
$Chlorides_{1:5}$ (mmol kg^{-1})	2.26
$Sulfates_{1:5}$ (mmol kg^{-1})	1.52
Ca^{2+} (mmol kg^{-1})	67.65
Mg^{2+} (mmol kg^{-1})	20.02
Na^{+} (mmol kg^{-1})	4.17
K^{+} (mmol kg^{-1})	6.07

* Cationic Exchange Capacity (CEC).

The irrigation water, from the Tajo-Segura water transfer system, had an average electrical conductivity ($EC_{25^\circ C}$) close to 1.3 dS m^{-1}. The irrigation system consisted of a single drip line per tree row and four pressure-compensated emitters (4 L h^{-1}) per tree located 50 and 130 cm from tree trunk to both sides of the tree.

Trees were fertilized with 83-56–109 kg ha^{-1} year^{-1} of N, P_2O_5, and K_2O, respectively, applied through the drip irrigation system [32]. Harvesting was done the first week of May. Other standard cultural practices such as winter pruning (during dormancy), thinning (March), and weed and pest control were done during the growing season and carried out by the technical department of the experimental station.

The experiment had a randomized complete block design with four replications. Each replication consisted of one row of twelve individual trees.

2.2. Meteorological Data

Agrometeorological data, including air temperature (T), relative humidity (RH), wind speed (u_2), global radiation, and precipitation were recorded following the World Meteorological Organization's recommendations by an automated station located at the CEBAS-CSIC experimental field station (http://www.cebas.csic.es/general_spain/est_meteo.html), 0.25 km from the orchard, which read values every 5 min and recorded the averages every 15 min. ET_0 (FAO-56, Penman– Monteith); daily maximum, minimum, and mean temperature (T_{max}, T_{mean}, T_{min}); and daily mean relative humidity (RH) were calculated and the daily mean vapor pressure deficit (VPD) was determined from daily values of maximum air temperature and minimum relative humidity.

2.3. Soil Water Content (SWC)

The volumetric soil water content was monitored with multi-depth EnviroScan®(Sentek Sensor Technologies, Stepney, Australia capacitance probes. Four PVC access tubes were installed 10 cm from the emitter located close (50 cm) to the tree trunk in four representative trees, one of each replication. Each capacitance probe had sensors fitted at 10, 30, 50, and 70 cm depth, and was connected to a radio transmission unit. Values were read every 5 min and the average recorded every 15 min. Probes were normalized and calibrated for a clay-loam soil [3,30,33]. Average SWC values in the 0–50 cm soil profile were calculated, since this depth corresponds to the maximum root density area [34]. Drip gauges were installed below the emitter with the capacitance probe to monitor real-time irrigation amounts in order to detect possible mishaps during the irrigation event.

2.4. Automated Irrigation Feedback

Automated irrigation to fulfil plant water requirements was based on real-time soil water content (SWC) values, measured with capacitance probes located in the main root zone (0–50cm), which acts on electro-hydraulic valves by means of a telemetry system. Threshold SWC values were established according to previous research results [33,35] corresponding to the management allowed depletion (MAD) as the desired soil water deficit at the time of irrigation of 10% from the fruit growth period to early post-harvest and 30% during the late post-harvest period to trigger irrigation and the field capacity (FC) value to end irrigation (Figure 1). It should be noted that irrigation events could occur at any time of the day. MAD was increased during the late post-harvest period, firstly to avoid the excessive vegetative growth (mainly water sprouts) that usually occurs during this period as well as to reduce the number of daily irrigation events caused by the high ET_0 values. The management allowable depletion (MAD, mm), was calculated using the following equation:

$$\text{MAD} = \alpha \times (\text{FC-WP}) \times z \quad (1)$$

where, FC is the field capacity, WP is the wilting point, α is the allowed soil water deficit proposed in our experiment, and z is soil depth (mm).

Automation was supported by add VANTAGE (by ADCON Telemetry), a web-based data visualization and processing platform of a wireless sensor network connected to radio-transmission units. The feedback routine for remotely triggering/stopping irrigation was configured on this platform under the 'condition' extension, acting on electro-valves. Irrigation water volume was measured with in-line water meters located at the beginning of the plot and connected to the telemetry system to detect any flow rate failure [3].

The irrigation factor (IF) was calculated as a dimensionless coefficient of applied irrigation divided by ET_0.

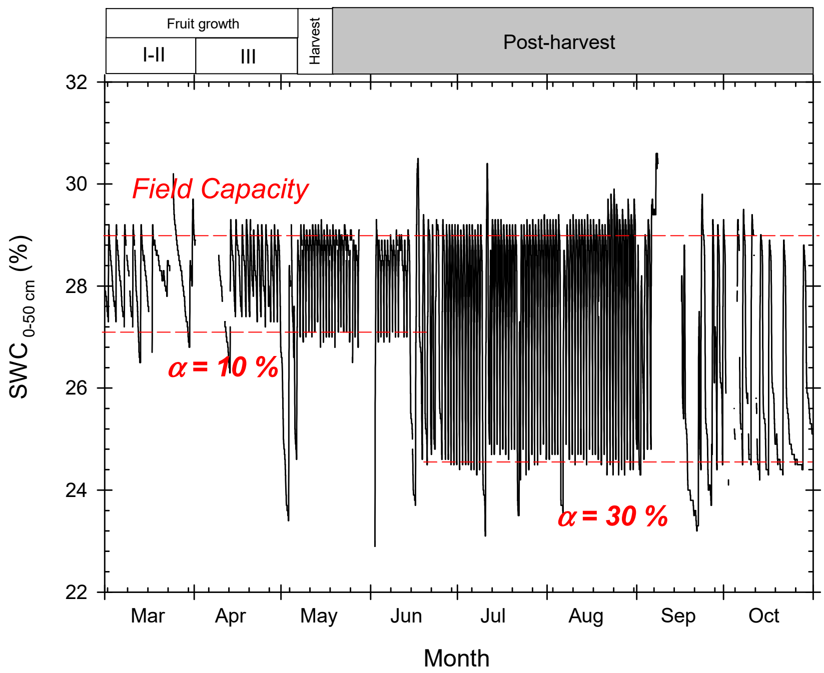

Figure 1. Average soil water content (SWC, %) during the irrigation season at the 0–50 cm layer of the soil profile. Dashed horizontal lines delimit field capacity and the allowed plant water deficit (α) imposed threshold values: 10% (fruit growth and early post-harvest) and 30% (late post-harvest) of field capacity, respectively. Phenological stages for nectarine trees are depicted in the top box.

2.5. Plant Measurements

Tree water status was evaluated weekly in one mature leaf per tree and replication (n = 4) by measuring midday stem water potential ($\Psi_{stem,}$ MPa) using a pressure chamber (Soil Moisture Equip rop. Model 3000, 153 Santa Barbara, CA, USA) at 12:00 h solar time. Mature leaves located on the north face of the tree and near the trunk were covered with aluminum foil bags for at least 2 h prior to the measurements, following the recommendations of [36].

Net CO_2 assimilation rate (A_{CO2}, μmol m^{-2} s^{-1}), maximum stomatal conductance (g_s, mmol m^{-2} s^{-1}), and transpiration rate (E_m, mmol m^{-2} s^{-1}) were measured in one mature leaf in full sun per replication (n = 4) at 10:00 h solar time at mean values of ambient photosynthetic photon flux density (PPFD) ≈ 1200 μmol m^{-2} s^{-1}, near constant ambient CO_2 concentration (C_a ≈ 400 μmol mol^{-1}), and leaf temperature (T_{leaf} ≈ 28 °C) obtained with a portable gas exchange system (LI-COR, LI-6400). Instantaneous water use efficiency (WUE) was calculated as the ratio between A_{CO2} and E_m (μmol $mmol^{-1}$).

Monthly vegetative growth was evaluated by measuring canopy tree cover development [37], determined by zenithal image analysis of photographs taken 7 m above the tree crown for four trees. The images were analyzed with the Corel PHOTO-PAINT X4 software.

3. Results and Discussion

3.1. Meteorological Conditions

The annual reference evapotranspiration was 1381 mm, whereas the total precipitation was 239 mm (Table 2). Monthly mean air temperature values of 10−14 °C in winter and 23−28 °C in summer were recorded. The seasonal pattern of monthly mean air vapor pressure deficit (VPD) and ET_0 was similar to that of the mean temperature, although a higher day-to-day variability was observed in the former (data not shown). Overall, the meteorological conditions registered were typical of Mediterranean areas, which are characterized by a high degree of seasonality summarized as hot and dry summers and cool and wet winters with high evaporative demand and low rainfall, normally below 250 mm [38,39], with the possibility of storm and hail events during spring and fall.

Table 2. Monthly crop reference evapotranspiration (ET_0); maximum, mean, and minimum air temperatures (°C); mean relative humidity (HR, %); mean vapor pressure deficit (VPD, kPa); precipitation (P, mm); mean wind speed at 2 m (u_2, km day^{-1}); and global radiation (W m^{-2}).

Month	ET_0 (mm)	Temperature (°C)			HR (%)	VPD (kPa)	P (mm)	u_2 (km day^{-1})	Global Radiation (W m^{-2})
		T_{max}	T_{mean}	T_{min}	*Mean*	*Mean*			
January	69.4	16.8	10.4	5.5	58.48	0.6	17.8	3.29	98.0
February	73.8	15.5	10.8	6.9	58.2	0.6	14.2	6.75	108.9
March	102.7	20.5	14.2	9.2	62.8	0.8	46.6	4.48	157.3
April	114.8	22.0	16.2	11.4	63.2	0.8	5.40	6.97	194.3
May	167.4	27.6	21.5	15.0	54.5	1.5	6.20	6.19	267.8
June	185.2	30.3	23.9	16.1	54.0	1.8	21.8	5.12	274.3
July	203.5	33.7	27.6	22.1	61.1	2.0	0.0	5.97	261.9
August	165.6	32.1	26.8	22.4	62.7	1.7	0.0	5.06	218.1
September	111.7	27.9	22.3	17.8	67.1	1.1	94.6	3.57	170.8
October	77.2	24.8	19.3	15.0	68.3	0.8	6.4	2.32	124.1
November	62.4	20.9	14.9	10.5	66.3	0.6	23.2	3.03	101.7
December	47.0	18.4	12.4	8.2	71.3	0.5	3.0	1.23	75.2
Total/Mean	1381.3	24.2	18.4	13.3	62.3	1.1	239.2	4.5	171.0

3.2. Soil Water Content (SWC) Pattern in the Soil Profile

The SWC values registered during the studied period, depicted in Figure 1, correspond to the maximum root density area of *Prunus* trees (0–50 cm), as indicated in previous research in similar edaphic-climatic conditions [34]. SWC values varied slightly and between the imposed threshold values to automatically start and end irrigation, demonstrating the suitability of the applied automated irrigation schedule. A 15 min delay in data relay was to be expected, but occasionally greater amplitude in SWC oscillations was observed, especially at the beginning of June (late post-harvest) coinciding with the change of α to 30 % and the increase in evaporative demand (Figure 1, Table 1). This post-harvest period is considered suitable for applying regulated deficit irrigation in early *Prunus persica* trees, because it is less sensitive to soil water deficits than the fruit growth period [40–45]. Post-harvest is the longest non-critical period, accounting for 80–86% of the water requirements needed for the entire irrigation season in these early *Prunus* cultivars [12,46], and it is important because carbohydrate reserves are accumulated and the floral differentiation process occurs during this time [47]. For these reasons, water deficits should be managed carefully in order to avoid severe plant water deficits, which would reduce bloom and fruit load in the next season's harvest [41,42,45,48,49].

The SWC pattern at different soil depths is depicted in Figure 2. Mean values varied around field capacity values (24–26%) with slight deficit levels (18% from FC) at 10 cm depth, which is the level that is most exposed to the water demands of the atmosphere and to root absorption. When precipitation events coincided with irrigation, the automatic system stopped irrigation as soon as the soil FC value was reached. It must be pointed out that only heavy precipitation events, such as those registered during spring (47 mm in March) and 87 mm in early September, induced significant increases in SWC values at 70 cm depth (Figure 2D), possibly causing some water losses outside of the area influenced by plant roots, but most of the time the SWC in the deeper soil layer remained consistent.

In line with these results, other studies have indicated that the monitoring of SWC with capacitive FDR probes provides accurate data in terms of precision, facility of calibration, installation and interpretation, and data transmission [29,30,35,48]. Continuous real-time measurements provide data on soil water content dynamics throughout the root zone and can be considered of value for efficiently scheduling the irrigation of horticultural crops [33,48,50,51].

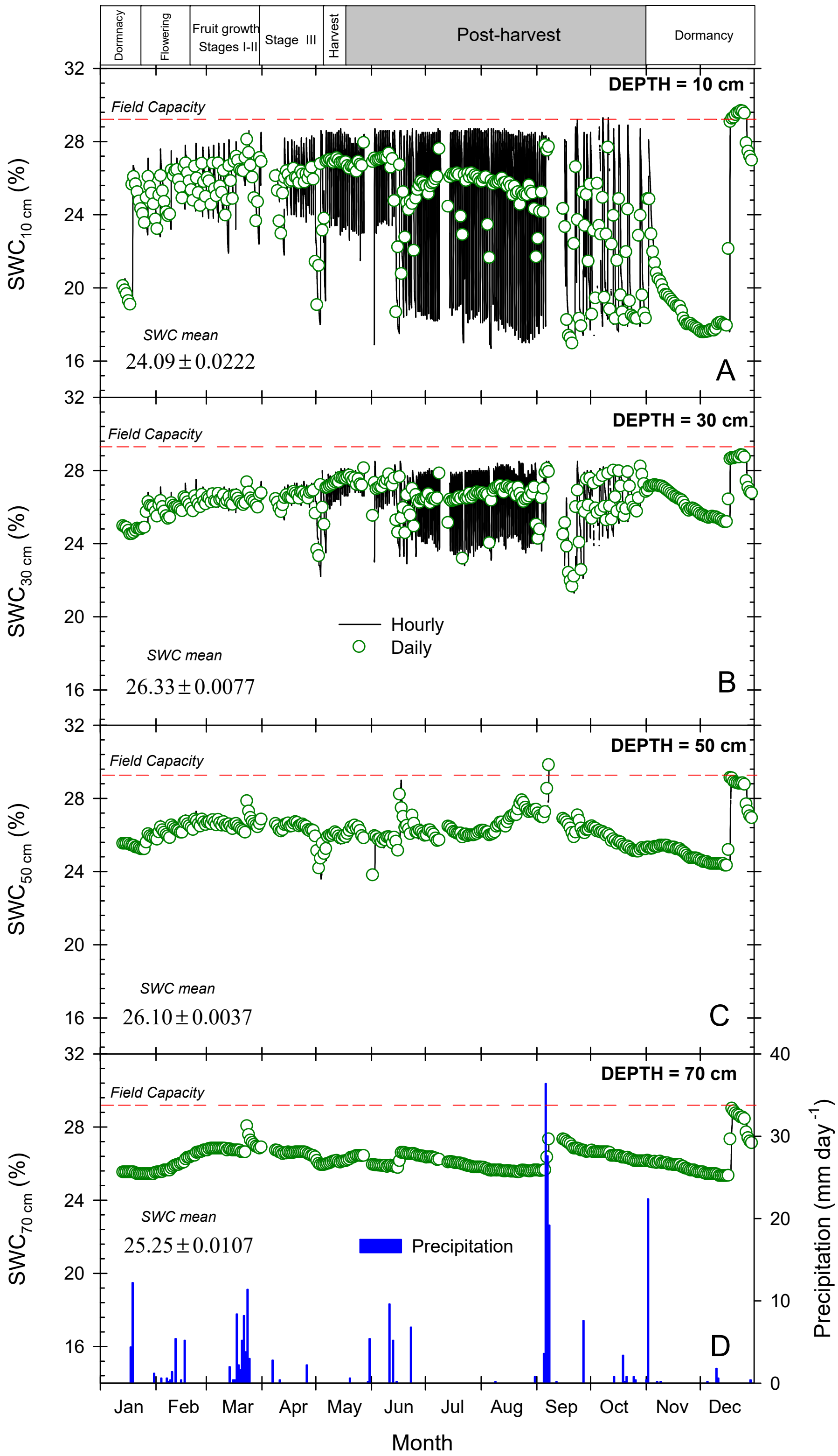

Figure 2. Soil water content (SWC, %) during the studied period at 10 cm (**A**), 30 cm (**B**), 50 cm (**C**), 70 cm (**D**) depth in the soil profile as 15 min recorded values (black line) and computed daily means (○ symbols). Vertical bars indicate the daily precipitation values (**D**). Horizontal bar delimits field capacity. Each point is the mean of four sensors. Phenological stages for nectarine trees are depicted in the top box.

3.3. Plant Water Relations

A non-flat pattern for stem water potential (Ψ_{stem}) was observed, with high values registered early in the season and a decreasing trend in summer (Figure 3A), as is characteristic of deciduous fruit trees [49,52], with an average mean value of −0.65 MPa, which is symptomatic of non-limiting soil water conditions in clay-loam soils [21,48,53–55]. Ψ_{stem} recovered during fall due to precipitation and mild meteorological conditions, emphasizing the resilient nature of this plant species [52]. A strong dependence was established between the Ψ_{stem} values and the VPD ($\Psi_{stem} = -0.75 \cdot VPD - 0.284$; $r^2 = 0.58$, ($p < 0.0001$)) (Figure 3A), as other authors have observed in fruit trees [17,21,52,56].

Mean seasonal values of net CO_2 assimilation rate (A_{CO2}) and stomatal conductance (g_s) were about 17 µmol m^{-2} s^{-1} and 280 mmol m^{-2} s^{-1}, respectively (Figure 3B,C). These values are in agreement with those reported in *Prunus persica* under non-limiting soil water conditions by other authors [57,58]. Both gas exchange parameters showed increasing values from the beginning of the season as leaves aged, with maximum values measured at harvest, after which photosynthetic activity tended to decrease due to a feedback effect of the fruit load on leaf photosynthesis [59–61]. Moreover, WUE increased in late post-harvest (Figure 3D), meaning that carbon fixation was higher than water losses through transpiration [62].

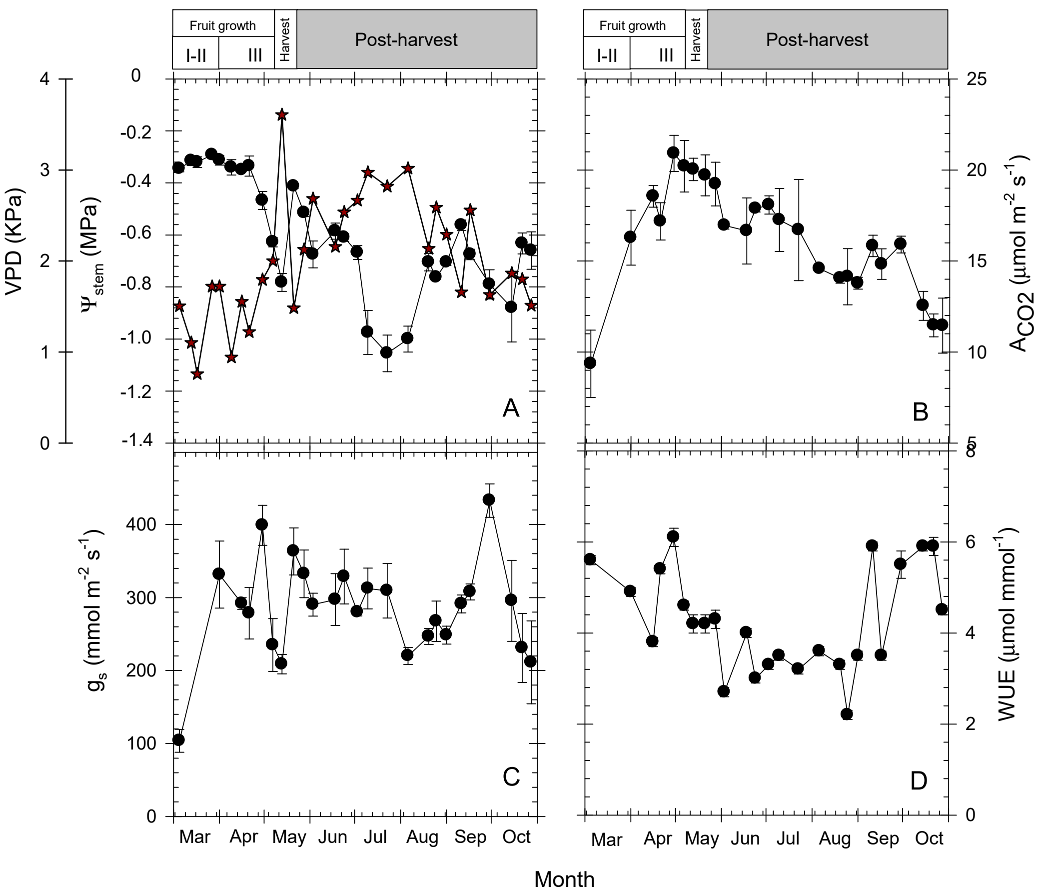

Figure 3. Mean values for (**A**) Midday stem water potential (•, Ψ_{stem}, MPa) and vapor pressure deficit (★, VPD, kPa), (**B**) Net CO_2 assimilation rate (A_{CO2}, µmol m^{-2} s^{-1}), (**C**) Stomatal conductance (g_s, mmol m^{-2} s^{-1}), and (**D**) Instantaneous water use efficiency (WUE, µmol $mmol^{-1}$) in early-maturing nectarine trees during the irrigation period. Points are mean ± SE (n = 4). Phenological stages for nectarine trees are depicted in the top box.

Seasonal plant water status and gas exchange values were above those considered, representing a plant water deficit situation (Figure 3) and confirming the well-adjusted irrigation protocol, which induced an adequate plant water status with no water stress indication.

3.4. Irrigation Factor (IF)

Once it was confirmed that irrigation scheduling clearly fulfilled nectarine water demand throughout the study period, as seen from soil and plant water relations (Figures 2 and 3), it was assumed that the ratio 'Irrigation/ET_0' could be taken as the irrigation factor (IF). Figure 4 shows IF values for the studied period, the low values corresponding to heavy precipitation events registered in spring and fall. The seasonal IF trend showed a close relation with the tree canopy cover development during the growing season, exhibiting their maximum values at the end of the summer (Figure 4). The adjusted IF values established a curvilinear regression [$y = 0.7418 - 0.0147 \cdot x + 0.00001 \cdot x^2 + 3.14 \cdot 10^{-7} \cdot x^3$; x = day of year; $r^2 = 0.90$; $p < 0.001$].

IF values were then obtained from the equation:

$$\text{Irrigation} = \text{IF} \times ET_0 \quad (2)$$

where ET_0 was obtained from a nearby agro-meteorological station.

For early-maturing nectarine trees, IF varies from 0.29 to 0.88, depending on the phenological period, which was well-defined by the accumulated growing degree-hours (GDH) (Table 3). Zapata et al. [63] used growing degree days (GDD) to identify the stages of fruit growth and crop development for stone fruit trees.

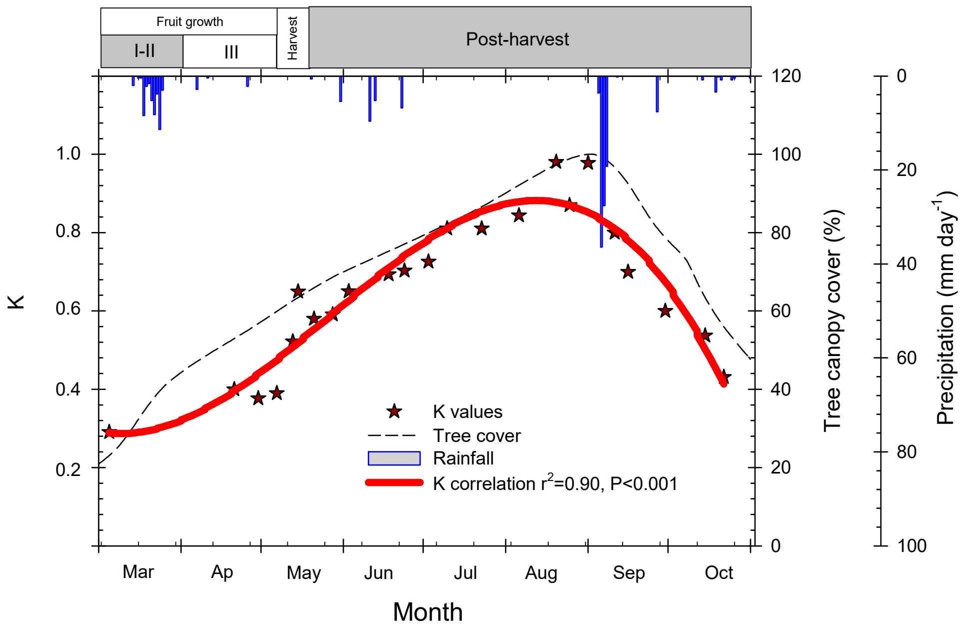

Figure 4. Seasonal evolution of irrigation factor (IF, ★), canopy tree cover (%, dashed line) for early-maturing nectarine trees, and daily precipitation (mm day^{-1}, vertical bars) during the irrigation period. The red line represents the adjusted IF values to a curvilinear regression. Phenological stages for nectarine trees are depicted in the top box.

The proposed irrigation factor integrated the crop coefficient (K_c) and the location coefficient (K_r), based on the percentage of shaded surface area (for young non-stabilized tree crops), as well as the application efficiency of the system. These coefficients must be taken into consideration in the calculation of irrigation requirements.

Therefore, the IF is assumed to integrate all of the coefficients:

$$IF = (K_{cb} + K_e)/AE \tag{3}$$

where K_{cb} is the basal crop coefficient that includes the K_r, K_e is the soil evaporation, K_r is the location coefficient, and AE is the application efficiency of the drip irrigation system used. The sum of K_{cb} and K_e represents the crop coefficient (K_c).

Most popular irrigation scheduling techniques calculate the irrigation dose based on a feed-forward strategy, which consists of applying irrigation to replenish the water used by the plants the previous day/week, using ET_c or water balance studies. This time-based system uses irrigation timers as a common part of automated irrigation systems. However, timers can lead to under- or over-irrigation if the water quantity is incorrectly calculated.

Some proposals have been made to use soil water content values with sensors for irrigation management. A soil water profile with a Gaussian bell shape was found when irrigation of peach trees was scheduled by ET_c, indicating some inaccuracy in the crop coefficient (K_c) value, recommending the use of feed-back approach [64]. In this framework, Abrisqueta et al. [41] described an automatic irrigation protocol in peach trees that started irrigation at 22:00 h if SWC was below field capacity and stopped when the sensor at 80 cm depth showed an increase of 2% over its value recorded at 22:00 h. This procedure induced a "divergent pattern" in SWC with a gradual decrease in SWC_{80}, so that increasingly higher levels were needed before the target was reached. Afterwards, different SWC threshold values were proposed by Vera et al. [48] based on the different degrees of sensitivity to water deficits during the phenological stages. Casadesús et al. [65] described automated drip irrigation scheduling in peach trees based on the SWC variations to fine-tune K_c values. Miller et al. [66] suggested pulsed irrigations based on MAD (maintained between 50% and 15%) for the automated irrigation of watermelons; when the given set point was detected, a 30 min irrigation cycle was initiated followed by a 1 h wait period. Furthermore, Osroosh et al. [67] compared several irrigation scheduling algorithms including (among others) soil-based granular matrix sensors and soil water balance, concluding that the latter seemed to be the most economical, easy to implement, and fairly accurate for automatic irrigation management of drip-irrigated apple trees.

Our findings indicated that the real-time SWC values, obtained from capacitance probes located at the maximum root exploration area, permitted the automation of irrigation without inducing water stress in fruit trees, providing irrigation factors that allowed precision irrigation in a practical, easy, and precise manner. Furthermore, when comparing K_c values from the literature with the experimental IF (Figure 5) for early-maturing *Prunus persica* trees, similar values were noted from the beginning of the season until harvest, with important deviations from those observed in FAO-56 [5] and other authors [10,12,68–70], which emphasizes the necessity of local experiments. The proposed IF permitted plant water requirements to be determined and irrigation to be managed with a hands-on approach, increasing the efficiency of water resources in a non-limiting soil water scenario, but without wasting water. This methodology is an easy and yet scientific way to determine the crop water requirements for specific hydraulic design, plant cultivar, and/or climate conditions, where K_c values are not available.

Annual water requirements for early-maturing nectarine trees in the agro-climatic region of Murcia (Ssoutheast Spain) were ≈ 660 mm, with an irrigation frequency varying from 1 to 7 days a week depending on the phenological period.

Applying the proposed IF, the water needs of early-maturing nectarine trees can be suitably adjusted to the local conditions of limited water resources.

Table 3. Proposed irrigation factor (IF) and accumulated growing degree hours (GDH) for the different phenological stages for early maturing nectarine trees.

Date	Irrigation Factor (IF)	GDH	Phenological Period	DAFB[1]
1–15 March	0.29	13,183	FGS[2] I (Thinning)	26
16–31 March	0.30	16,781	FGS II	38
1–15 April	0.34	20,837	-	-
16–30 April	0.41	25,946	FGS III	56
1–15 May	0.48	30,441	Harvest	75
16–31 May	0.57	36,213	Early post-harvest	90
1–15 June	0.66	41,330		
16–30 June	0.73	45,593	Late post-harvest	120
1–15 July	0.80	49,116	-	-
16–31 July	0.85	52,275	-	-
1–15 August	0.88	55,274	-	-
16–31 August	0.87	59,606	-	-
1–15 September	0.82	64,913	-	-
16–30 September	0.73	70,230	-	-
1–15 October	0.59	75,767	-	-
16–31 October	0.47	81,659	-	-

[1]DAFB: days after full bloom (occurring 9th February = 40th day of the year). [2]FGS: Fruit growth stage.

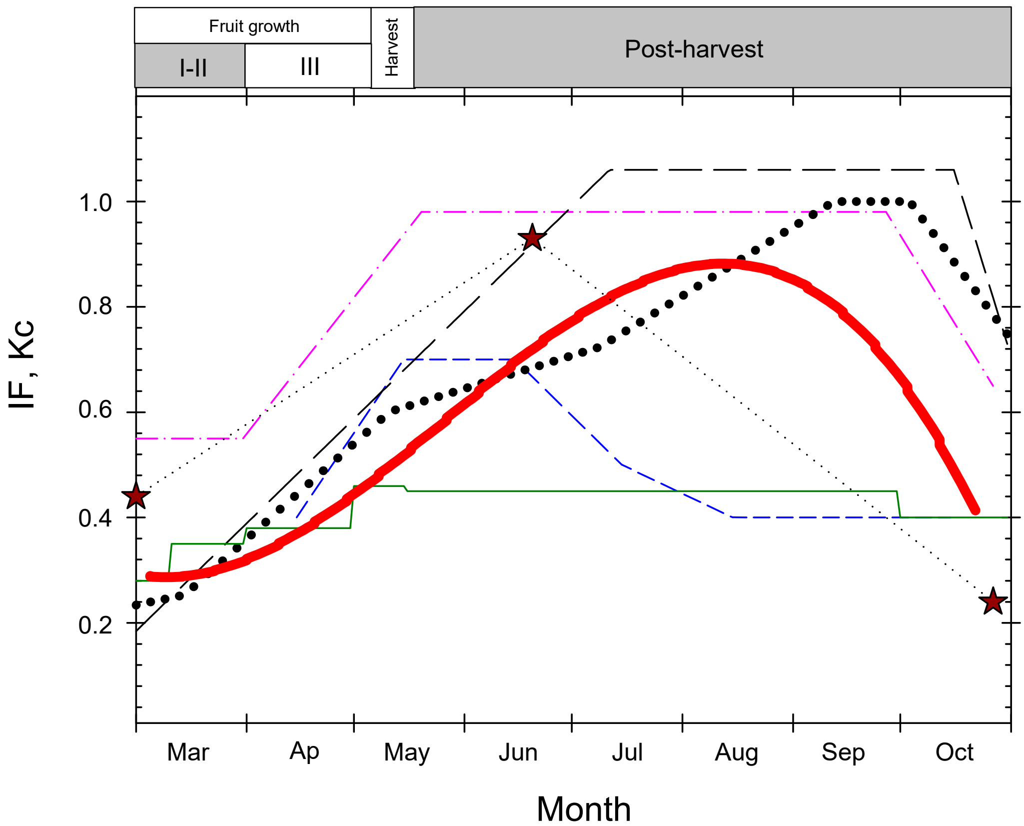

Figure 5. Seasonal Irrigation factor proposed (IF) (▬), and crop coefficient (Kc) proposed for *Prunus persica* cultivars by: FAO-56 [5] (–·–·–), Abrisqueta et al. [12] (•••••), Ayars et al. [10] (– – –), García-Vera and Martínez-Cob [68] (···★···), Haifa Chemical ltd. [69] (– – –), and Sistema de Información Agraria de Murcia [70] (——).

4. Conclusions

Capacitance probes have become a useful tool for monitoring soil water content. When threshold SWC values were precisely defined with respect to field capacity, the slight water depletion observed in the soil did not provide evidence of a significant plant water deficit. Irrigation factors (IF) are presented for early-maturing nectarine trees cultivated under Mediterranean conditions as a useful tool for efficient irrigation management which might be adopted by farmers using a hands-on approach. There is general agreement on the potential for saving water, energy, and labor of precision irrigation, and the transfer of the technology to the irrigation community would represent a step forward in irrigated agriculture.

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