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Setting Irrigation Thresholds for Building a Platform Aimed at the Improved Management of Citrus Orchards in Coastal Syria

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Abstract: Citrus is one of the most valuable crops in Syria, with the largest production areas being in the coastal provinces of Tartus and Latakia, where this study was performed. A companion paper reported on the basal crop coefficients derived from the field water balance and on the performance assessment of various irrigation methods used in a citrus orchard located in the same region. That study evidenced the need for the improved management of irrigation water, mainly reducing water applications and increasing productivity, thus leading to the current research. The main objectives consisted of (i) providing a set of reliable basal (K_{cb}) and average (K_c) crop coefficients to be used in practice in the citrus orchards of the Syrian coastal area, while accounting for the diversity of characteristics observed; (ii) to estimate the seasonal consumptive use of typical orchards under different climate-demand and deficit-irrigation scenarios; and (iii) to assess possible water savings and related yield reductions. The previously calibrated water balance model SIMDualKc was used for these purposes. The computed K_{cb} values for the mid-season and average demand for water ranged from 0.52, when the plant density was low, to 0.84, when plant density was very high. The corresponding K_c values, which further reflected the impact of drip irrigation on controlling soil evaporation, were 0.72 and 0.97, respectively. Overall, the consumptive use of water was estimated to range from 867 to 1573 mm. The assessed water-saving scenarios consisted of adopting increased management-allowed depletion (MAD) thresholds relative to the p depletion fraction for no stress: MAD = 1.05, 1.10, 1.20, and 1.30 p. For trees under a very high climatic demand, water savings ranged from 12 to 34%, but the yield losses induced by the water deficits ranged from 8 to 48%. Although the selection of optimal strategies should be based upon economic terms, these may only be used when the Syrian economy recovers from civil war and the current crisis. The present results show the feasibility of adopting such MAD thresholds for building an irrigation management platform. The data provided by the current study are valuable because they can be efficiently used to support of the irrigation management of Syrian citrus production systems.

Keywords: A&P approach; climatic demand variability; crop density; deficit irrigation; impacts on yields; SIMDualKc model; water saving

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1. Introduction

Syria is one of the main citrus producers in the Mediterranean region, with orange production averaging 0.67 M tons year^{-1} and lemon and lime yielding 0.36 M tons year^{-1} from 2016 to 2020 [1]. Before war times, citrus production counted as an important income source for the country, representing 1.3% of the gross domestic product, 20% of the value of national fruit and vegetable exports, and 0.8% of the world global production [2]. With the war, exports drastically dropped, and citrus production has been mostly for domestic consumption [3].

The Syrian citrus cultivated area is mainly located in the Tartus and Latakia provinces, totalizing close to 42,700 ha. In the coastal region, these provinces combine favorable environmental conditions for citrus production, namely mild winters, high humidity for most of the year, annual rainfall often above 800 mm, and water availability for irrigation during the dry summer season [2]. Drip irrigation is used in 43% of the irrigated land area [4], greatly contrasting with the rest of the country, where traditional irrigation methods are still the common rule.

In an effort to rationalize agricultural water use in Syria, several studies were carried out over the last decades to rationalize agricultural water use and control the overexploitation of available water resources [5,6]; improve irrigation water management practices through the accurate estimation of crop water requirements, using the soil water balance SIMDualKc [7,8]; increase land and water productivity and farmers' income [9,10]; and assess the water, yield, and economic performance of modernized irrigation systems [11–13].

The FAO56 method remains the most widely used approach for estimating crop water requirements, i.e., the crop evapotranspiration (ET_c) [14]. The ET_c is the product of the grass reference evapotranspiration (ET_o), representing the evaporative demand of the atmosphere and defined with the FAO Penman–Monteith (PM) equation, and a crop coefficient (K_c), representing the effect of the difference in terms of ET rate between the crop under study and under pristine, eustress conditions, and the reference crop, for which the ET rate is the ET_o. K_c values, which are described by a K_c or a K_{cb} curve, vary with crop species and crop stages [14]. When adopting the single K_c approach, an average value combining soil evaporation and crop transpiration is assumed. If ET_c is partitioned into the basal transpiration coefficient (K_{cb}) and the soil evaporation coefficient (K_e), the dual crop coefficient approach is adopted ($K_c = K_{cb} + K_e$).

The FAO56 methodology is somewhat challenging for orchards and grape vines because these are complex systems, with heterogeneous surfaces and incomplete ground cover. Differences in the planting density, canopy height, training system, interrow management, and irrigation method influence the amount of energy available for both the transpiration and the soil evaporation processes [15]. In addition, the best crop management often corresponds to adopting controlled/regulated water deficit at given periods for water saving and enhance the quality of fruits [16], referred to as the eustress conditions. To more easily account for the variability of conditions influencing K_c in orchard systems, Allen and Pereira [17] developed an approach (hereafter denoted as the A&P approach) to compute the K_{cb} from observations of the fraction of the ground covered by the vegetation (f_c) and plant height (h) that estimate a density coefficient, as well as by the degree of stomatal adjustment (F_r) and the opacity of the canopy (ML). Pereira et al. [18] revisited the A&P approach and tested its performance relative to a large number of annual and perennial crops, comparing the K_{cb} values obtained with the A&P approach with those derived from ET field research. The results, namely for trees, showed excellent predictions of the K_{cb} by the A&P approach. In their study, Pereira et al. [19] tabulated the parameters to be used with the A&P approach when targeting standard K_{cb} values. Moreover, Pereira et al. [18] also analyzed the performance of A&P to estimate K_{cb} when f_c and h are obtained from remote sensing. This approach is used in California's SIMS together with ET_o from CIMIS to compute the ET_c for irrigation advising, resulting in a small mean bias error of 6.9% for trees and vines.

The methodology based on the dual K_c approach and the A&P approach shows a good potential for application to the coastal citrus orchards of Syria, namely using ground observations instead of remote sensing. The innovation required includes assigning characteristics of orchards, namely those relative to K_{cb}, to the various orchards. Once this is achieved, it is possible to simulate the water balance of the citrus depending on the characteristics and the K_{cb} of orchards, either in real time or relative to various water-demand scenarios. The companion paper by Darouich et al. [20] followed the research referred to above and consisted of the first part of the study on improved irrigation of citrus orchards to be continued through this article. Using the software SIMDualKc, Darouich et al. [20] developed a soil water balance of a clementine orchard, derived its crop coefficients (K_c) relative to various irrigation methods (drip, bubblers, micro-sprinkler, and ring basin), and assessed the performance of those methods, but focusing on drip irrigation positive impacts on the non-beneficial uses of water in citrus orchards, i.e., by decreasing evaporation losses during the dry summer season due to the small area wetted by drippers when compared with other methods. That study also showed the impact of canopy cover, tree height, and irrigation method on crop coefficients, and the impact was confirmed later by the standard K_{cb} of vineyards [21], as well as for citrus and various Mediterranean crops, using the published data of more than one hundred papers reporting good-quality field research [22]. Numerous applications of the A&P approach to tree crops have been reported, e.g., by Paço et al. [23] for peach; Paço et al. [24] and Puig-Sirera et al. [25] for olive; Vinci et al. [26] for hazelnut; and Mobe et al. [27] for various apple orchards in South Africa. Applications to vineyards include Williams et al. [21], who reported on a survey of California vineyards, using A&P. The applications to citrus are also numerous [28–32]. These applications make us confident about the effectiveness of using the A&P approach.

The current study, which serves as a companion study to that of Darouich et al. [20], aimed at further assessing appropriate issues to implement water-saving irrigation in the coastal Tartus and Latakia citrus orchards by focusing on irrigation scheduling in combination with drip irrigation. Considering the previous calibration and validation of SIMDualKc, as well as the careful definition of the orchards, water-saving thresholds, and atmospheric demand for water, the results of the simulations performed consist of effective information tools for irrigation scheduling thresholds to be used in practice. Moreover, the SIMDualKc is a well-proved SWB software model that, in addition to support deriving K_{cb} and K_c values, has been previously used to search for crop and irrigation practices that could control the water demand of maize and pea for industry [33,34]. In these applications, the model was first calibrated and validated using field data, the SWB was performed, and the debilities of the current irrigation management were identified, together with possible issues for improvement. Once the model was properly calibrated, simulations were performed to assess the top issues for irrigation and crop management, namely relative to irrigation scheduling and planting dates. Similar studies have been performed with tree crops after being adapted to the orchard and crop characteristics [25,35–38]. SIMDualKc applications include Rosa [29] for lemon and pear, Peddinti and Kambhammettu [39] for citrus, Cao et al. [40] for apple, Fandiño [41] for grapes, and Vinci et al. [26] for hazelnut. Naturally, despite the fact that the objective of improving agricultural water management is basically common, the orchard characteristics and research tools and practices used were different, thus implying innovative approaches for every application.

The main objective of this study was, therefore, to further pursue the work performed by Darouich et al. [20] by developing tools to improve the management of irrigation water in citrus orchards located in the Syrian coastal region. The specific objectives were (i) to derive K_{cb} and K_c values for the various citrus orchards, using the A&P approach; (ii) from those K_{cb} and K_c, to compute the crop transpiration (T_c), crop evapotranspiration (ET_c), and irrigation water needs in Syrian citrus orchards, while considering different crop densities, water-shortage conditions, and climate variability (1988–2022); and (iii) to estimate yield reductions from adopting different water-saving irrigation strategies. The immediate results of this study contribute to overcoming the existing knowledge gap in the region in terms of rational data for effective use in irrigation water management, including in real time after the war ends. The ultimate objective is, therefore, the development and implementation of water-saving irrigation practices in the Syrian coastal region, contributing to the sustainability of local soil and water resources.

2. Materials and Methods

2.1. Study Area

The study area is the Tartus and Latakia provinces (Figure 1), which concentrate, respectively, 82% and 17% of the citrus production in Syria [42]. In all, 60% of the total production corresponds to orange (*Citrus sinensis* (L.) Osbeck), 12% to lemon (*Citrus limon* (L.) Osbeck), and 22% to clementine (*Citrus clementina* Hort.) and other species [4]. The climate in the region is hot-summer Mediterranean (Csa) [43]. Considering the period from 1998 to 2020, the mean annual air temperature is 19.3 °C. The mean monthly values vary from 11.5 °C in January to 27.0 °C in August. The mean annual precipitation is 930 mm and occurs mostly between October and May. The annual reference evapotranspiration (ET_o) averages 1363 mm. The dominant soil reference groups are Vertisols, Cambisols, and Luvisols [44]. Irrigated agricultural land covers 29,100 ha in the Tartus district and 38,000 ha in the Latakia district [4]. Irrigated water is mainly withdrawn from surface water resources. The water-table depth varies from 10 to 20 m.

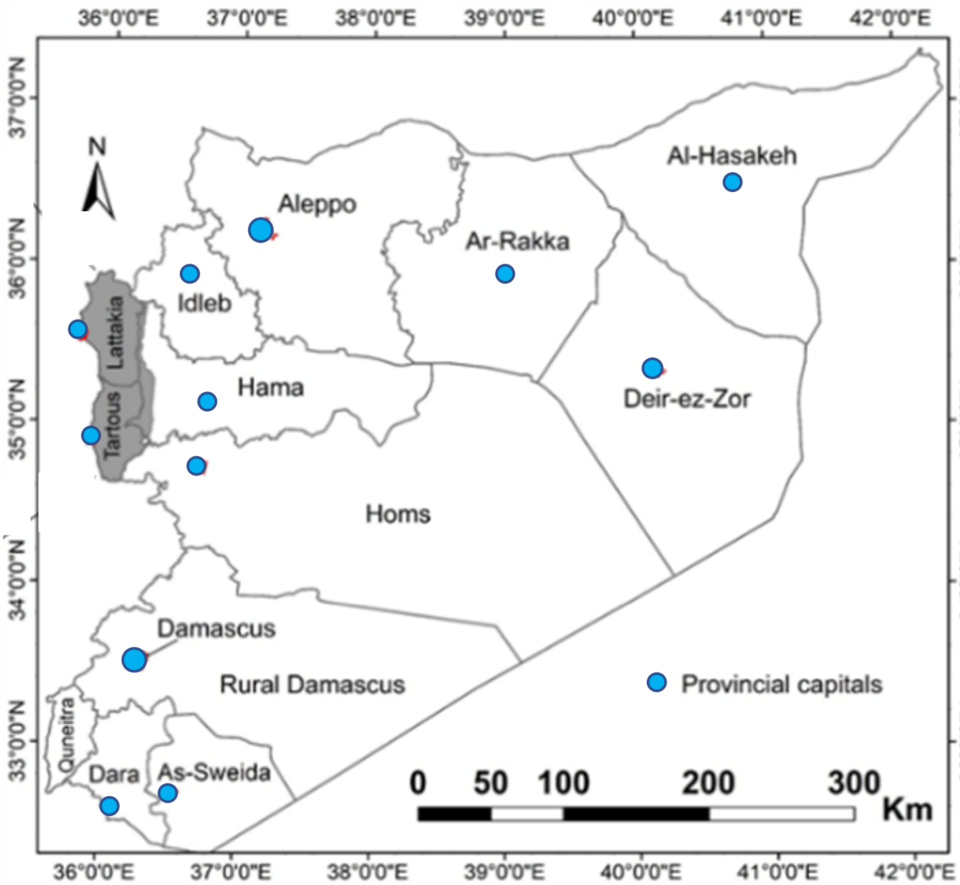

Figure 1. Location of the Tartus and Latakia provinces (adapted from Mohamed [45]).

2.2. The A&P Approach

Allen and Pereira [17] proposed an empirical procedure for estimating K_{cb} values for the different stages of development of natural vegetation, tree orchards, and landscape systems based on the amount of vegetation present in those systems and background soil evaporation. In this approach, the transpiration component of the evapotranspiration process, represented by the K_{cb}, is related to the amount of vegetation of the crop density coefficient (K_d):

$$K_{cb} = K_{c\ min} + K_d (K_{cb\ full} - K_{c\ min}) \quad (1)$$

where K_d is the density coefficient that represents the impacts of plant density and/or leaf area, $K_{cb\ full}$ is the estimated basal K_{cb} for plant-growth conditions having nearly full ground cover (or LAI > 3), and $K_{c\,min}$ is the minimum K_c for bare soil (in the absence of vegetation).

When natural vegetation or grass covering the row and interrow of orchards is observed, Equation (1) is modified to account for the impact of those plants on the total evapotranspiration of the orchard system [17,46]:

$$K_{cb} = K_{cb\,cover} + K_d \max\left[(K_{cb\,full} - K_{cb\,cover}), \frac{K_{cb\,full} - K_{cb\,cover}}{2}\right] \quad (2)$$

where $K_{cb\,cover}$ is the K_{cb} of the ground cover in the absence of tree foliage, K_d is the density coefficient, and $K_{cb\,full}$ is the basal K_{cb} anticipated for the crop under full-cover conditions and corrected for climate. The second term of the max function, which accounts for the effects of shading by the active ground cover, reduces the estimated K_{cb} by half the difference between $K_{cb\,full}$ and $K_{cb\,cover}$ when this difference is negative. The value for $K_{cb\,cover}$ in Equation (2) should represent the K_{cb} of the surface cover in the absence of tree cover; it should therefore reflect the density and vigor of the surface cover, as in areas exposed to sunlight.

The density coefficient K_d is estimated from observations of the fraction of the ground covered by vegetation (f_c) and plant height (h) and describes the increase in K_c with increases in the amount of vegetation. K_d is estimated as follows [18]:

$$K_d = \min\left(1, M_L\, f_{c\,eff}, f_{c\,eff}^{\left(\frac{1}{1+h}\right)}\right) \quad (3)$$

where $f_{c\,eff}$ is the effective fraction of the ground covered or shaded by vegetation (0.01–1) near solar noon, M_L is a multiplier on $f_{c\,eff}$ describing the effect of canopy density on shading and maximum relative ET per fraction of shaded ground [1.0–2.0], and h is the mean height of vegetation (m).

The $K_{cb\,full}$ value represents the upper limit of the system and is estimated as follows:

$$K_{cb\,full} = F_r\left(\min(1.0 + k_h\, h, 1.20) + [0.04(u_2 - 2) - 0.004(RH_{min} - 45)]\left(\frac{h}{3}\right)^{0.3}\right) \quad (4)$$

where u_2 is the mean daily wind speed at a 2 m height (m s^{-1}) during the growth period, RH_{min} (%) is the mean daily minimum relative humidity during the growth period, and h is the mean plant height (m) during mid-season. Before climatic adjustment, the upper limit for $K_{cb\,full}$ is 1.20. The effect of crop height is considered through the sum (1 + k_h h), with k_h = 0.1 for tree and vine crops [18]. Higher $K_{cb\,full}$ values are expected for taller crops and when the local climate is drier and/or windier than the standard climate conditions (RH_{min} = 45% and u_2 = 2 m s^{-1}) adopted in FAO 56. When the vegetation shows greater stomatal adjustment upon transpiration, parameter F_r applies an empirical adjustment (F_r < 1.0); otherwise, F_r = 1.0. For trees and vines, F_r is closer to 1.0 when crops exhibit great vegetative vigor; F_r decreases with limited water supply and due to pruning and training when the crop is stressed, and stomatal adjustment occurs. The F_r is defined as follows [18]:

$$F_r = \frac{\Delta + \gamma(1 + 0.34\, u_2)}{\Delta + \gamma\left(1 + 0.34\, u_2 \frac{r_l}{r_{typ}}\right)} \quad (5)$$

where r_l and r_{typ} are, respectively, the estimated actual mean leaf resistance and the typical leaf resistance (s m^{-1}) for the vegetation in question. Moreover, Δ is the slope of the saturation vapor pressure vs. air temperature curve (kPa °C^{-1}), and γ is the psychrometric constant (kPa °C^{-1}), both relative to the period when $K_{cb\,full}$ is computed. When standard K_{cb} values are considered, e.g., as initial values of K_{cb} for calibration purposes, F_r = 1.0 is assumed. Differently, when searching for actual K_{cb} values, F_r < 1.0 may be estimated with support of the tabulated values in Pereira et al. [18].

The application of this approach does not require calibration/validation if using the tabulated parameters in Pereira et al. [19]. Nevertheless, when field data are available, a validation may be performed by comparing the K_{cb} values derived from the A&P approach with those computed from field data, as already performed for the study area by Darouich et al. [20].

2.3. Management Scenarios

The soil water balance was computed for different orchard scenarios related to planting density, climate demand, and irrigation strategies. For each scenario, the crop evapotranspiration was computed by combining the A&P approach for assessment of the transpiration component according to scenario characteristics, and simulations of the SIMDualKc model for assessment of the soil evaporation component. Both methodologies were previously calibrated/validated in the companion study [20], therefore providing reliable estimates for both components in the study area.

Citrus orchards in the Syrian coastal area were divided into three major groups based on flowering and harvesting dates:

- Group 1 (G1) includes clementine and mandarin species, with flowering by March and harvesting from September to October [20].
- Group 2 (G2) refers to sweet orange, with flowering in May and the harvest from November to January [47,48].
- Group 3 (G3) includes lemon and lime species. Three flowering periods were considered (April, May, and November), and the harvest was throughout the year [29,49].

Each group was divided into 5 subgroups (Table 1), accounting for the density of citrus orchards, which were characterized based on representative f_c and h values observed in the region, as well as the F_r values tabulated in Pereira et al. [19]. This information was used to estimate the K_{cb} values for each orchard following the A&P approach.

Table 1. Scenarios of plant density of citrus orchards.

Orchard	h (m)	f_c (-)	F_r (-)
Low density, tall tree	4.5	0.40	0.63
Med density, small tree	3.5	0.65	0.53
Med density, tall tree	4.5	0.65	0.57
High density, small tree	3.5	0.70	0.61
High density, tall tree	4.5	0.70	0.78

Note: h, plant height; f_c, the fraction of the ground covered by vegetation; F_r, empirical parameter.

The net irrigation water requirements were estimated by computing the daily soil water balance using the SIMDualKc model [50], which was used in the companion paper by Darouich et al. [20]. The model adopts the FAO56 dual K_c approach, thus partitioning evapotranspiration fluxes into its components, namely crop transpiration (T_c) and soil evaporation (E_s) [14,51]. The SIMDualKc model has proved to be quite precise for computing crop evapotranspiration and performing the water balance to assess crop irrigation requirements, as analyzed by Pereira et al. [52] and referred to in the Introduction. The model was calibrated and validated for citrus, as reported in the companion paper (Darouich et al. [20]), where a complete description of the model and of its performance is provided. Therefore, because the companion paper is open access, a full description of the model and of its application is not given here.

In the current study, while the K_{cb} values were provided by the A&P approach, allowing the direct estimate of the T_c component, the E_s component required the daily computation of the soil water balance of the soil evaporative layer, which was performed with the SIMDualKc model. The parametrization of irrigation followed observations reported in the companion paper [20]. Drip irrigation was used. The wetted fraction (f_w) was small, up to 0.25. In all scenarios, the net irrigation depths were fixed at 5 mm per event, except for the case of high-density and tall trees, for which the application depths were fixed to 10 mm to compensate for the higher irrigation demand.

Simulations were performed for the period 1998–2022 (25 years). Daily meteorological data were taken from the Zahid station (34°41′37″ N, 35°59′16″ E; 12 m a.s.l.), which was considered to be representative of the Syrian coastal area. The data included the minimum and maximum air temperatures (T_{min} and T_{max}; °C), precipitation (P; mm), minimum and maximum relative humidity (RH_{min} and RH_{max}; %), number of sunshine hours (I_{sun}; h), and wind speed at 2 m height (u_2; m s^{-1}). As in Darouich et al. [8], missing u_2 values in 2011–2013 and 2015 were filled with wind data from the closest weather station (Trípoli, Lebanon), following the recommendations in FAO56. Figure 2 presents a brief characterization of the weather data used, as well as the annual precipitation and ET_o variability throughout the study period.

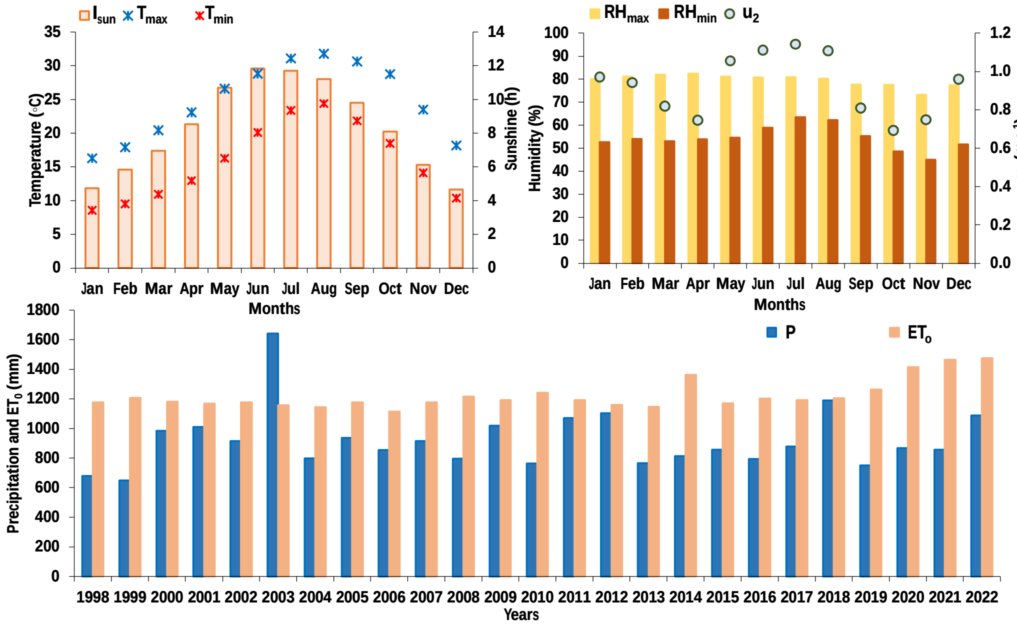

Figure 2. Above: monthly averages of maximum and minimum air temperatures (T_{max} and T_{min}; °C), maximum and minimum relative humidity (RH_{max} and RH_{min}; %), number of sunshine hours (I_{sun}; h), and wind speed at a 2 m height (u_2; m s^{-1}). Below: annual precipitation (mm) and annual grass reference evapotranspiration (ET_o; mm); all data are for the period 1998–2022.

To build the climate scenarios, data were then ordered from the lowest to the highest based on atmospheric demand (annual ET_o). The years with the probability of occurrence of 20%, 50, 80%, and 95%, corresponding to low (2012), medium (2011), high (2010), and very high (2022) atmospheric demand, were then selected for the analysis.

The dates of the crop stages were defined based on the growing-degree days reported in the companion paper [20]. The dates of the initial stage were set following an analysis of the daily air temperatures at the beginning of the year. Table 2 presents the dates of the crop stages for every citrus orchard and climate scenario considered in this study. The parametrization of soil properties also followed observations reported in the companion paper [20]. The soil at the Zahid station was assumed to represent the study region, namely relative to the total and readily available water (TAW and RAW; mm). The soil water balance simulations were performed using the calibrated parameters of runoff (CN) and deep percolation functions (a_D and b_D), the soil water depletion fraction for no stress (p), the total and readily evaporable water (TEW and REW; mm), and the thickness of the soil evaporation layer (Z_e; mm). The model parameters are given in Table 3.

Deficit-irrigation/water-saving scenarios were defined to improve irrigation water use while further considering the expected increasing scarcity of water in the region. Irrigation schedules were defined by imposing a water deficit of 5%, 10%, 20%, and 30% of p, the soil water depletion fraction for no stress. These values define the irrigation trigger thresholds, i.e., the management-allowed depletion (MAD) = 1.05 p, 1.10 p, 1.20 p, and 1.30 p, respectively.

Table 2. Dates of the crop stages for each citrus group (G1–G3) and climate-demand scenario (low, medium, high, and very high demand).

Demand Scenario	Non-Growing	Initial	Crop Development	Mid-Season	Late-Season	End-Season
G1:						
Low	01-Jan	20-Feb	14-Mar	15-Jun	05-Oct	31-Dec
Medium	01-Jan	01-Feb	15-Feb	01-Jun	01-Oct	31-Dec
High	-	01-Jan	31-Jan	21-May	01-Oct	31-Dec
Very high	-	01-Jan	22-Feb	29-May	19-Sep	31-Dec
G2:						
Low	01-Jan	20-Feb	21-Mar	21-Jun	01-Nov	31-Dec
Medium	01-Jan	19-Jan	01-Mar	15-Jun	24-Oct	31-Dec
High	01-Jan	15-Jan	01-Mar	15-Jun	01-Nov	31-Dec
Very high	01-Jan	06-Feb	29-Mar	19-Jun	01-Nov	31-Dec
G3:						
Low	01-Jan	19-Feb	31-Mar	06-Jun	15-Sep	31-Dec
Medium	01-Jan	01-Mar	22-Mar	27-May	15-Sep	31-Dec
High	01-Jan	14-Feb	08-Mar	22-May	05-Sep	31-Dec
Very high	01-Jan	12-Feb	04-Apr	22-May	05-Sep	31-Dec

Table 3. Calibrated model parameters (from Darouich et al. [20]).

Parameter	Symbol	Value
Depletion fraction for no stress	p_{ini}	0.60
	p_{mid}	0.60
	p_{end}	0.60
Total evaporable water	TEW (mm)	40
Readily evaporable water	REW (mm)	8
Depth of the soil evaporation layer	Z_e (m)	0.10
Deep percolation	a_D	490
	b_D	−0.02
Runoff curve number	CN	80

2.4. Evaluation of Yield Decline in Relation to Deficit-Irrigation Management

For each scenario, the linear crop water-yield function (Doorenbos and Kassam [53]) was used to assess the impact of the proposed deficit-irrigation schedules on crop yields, as follows:

$$\left(1 - \frac{Y_a}{Y_m}\right) = K_y\left(1 - \frac{ET_{c\ act}}{ET_c}\right) \tag{6}$$

where Y_a and Y_m are the actual and maximum crop yields, respectively; $ET_{c\ act}$ and ET_c are the corresponding actual and potential seasonal crop evapotranspiration, respectively; and K_y is the yield response factor describing the reduction in relative yield due to the reduction in ET caused by the soil water shortage. The K_y values were defined for the mid-season stage. For the citrus species in G1 (clementine and mandarin) and G2 (sweet orange), K_y = 1.1 was assumed, considering their relatively high sensitivity to water stress [53–55]. The species in G3 (lemon) were assumed to exhibit a greater tolerance to water stress; thus, K_y = 0.9 was adopted [29,49]. Following Manssur [42], the Y_m values were set to 30, 40, and 30 tons ha^{-1} for the crops in G1, G2, and G3, respectively. However, it is well-known that yields change with variety, crop management, environmental conditions, irrigation management, pests and diseases, and other factors.

3. Results and Discussion

3.1. Crop Coefficients for Citrus Orchards

The basal crop coefficients (K_{cb}) computed for the different crop stages using the A&P approach are shown in Table 4.

Table 4. Basal crop coefficients (K_{cb}) and mean crop coefficients (K_c) for orchards under different planting densities and climate scenarios (low, medium, high, and very high demand).

Scenario	Initial		Mid-Season		Late Season	
	K_{cb}	K_c	K_{cb}	K_c	K_{cb}	K_c
Low Density						
Low	0.50	1.12	0.50	0.70	0.49	1.09
Average	0.50	1.15	0.52	0.72	0.50	1.12
High	0.48	1.12	0.53	0.73	0.51	1.16
Very high	0.54	1.25	0.56	0.78	0.54	1.21
Med density, small tree						
Low	0.55	0.95	0.52	0.67	0.53	0.91
Average	0.55	0.97	0.55	0.71	0.55	0.97
High	0.53	0.93	0.55	0.72	0.56	0.98
Very high	0.59	1.04	0.59	0.77	0.59	1.03
Med density, tall tree						
Low	0.60	1.00	0.56	0.71	0.58	0.96
Average	0.60	1.02	0.59	0.75	0.60	1.01
High	0.57	0.97	0.60	0.77	0.61	1.04
Very high	0.64	1.09	0.64	0.82	0.65	1.09
High density, small tree						
Low	0.64	0.99	0.61	0.75	0.62	0.95
Average	0.64	0.99	0.63	0.78	0.64	0.98
High	0.62	0.97	0.64	0.79	0.66	1.03
Very high	0.68	1.06	0.68	0.86	0.69	1.06
High density, tall tree						
Low	0.84	1.17	0.79	0.93	0.81	1.11
Average	0.84	1.16	0.82	0.97	0.84	1.16
High	0.80	1.15	0.84	1.00	0.86	1.20
Very high	0.90	1.27	0.89	1.06	0.91	1.25

A single average value is presented for each stage following the single F_r values tabulated in Pereira et al. [19], which are not different among the citrus species; further field studies will provide different F_r values. Table 4 further includes the mean crop coefficient (K_c) for the different crop stages, thus also including the evaporation coefficient (K_e) derived from the computation of the daily soil water balance using the SIMDualKc model.

Estimates of the K_{cb} values provided by the A&P approach were already validated in Darouich et al. [20], returning the same or very similar values as those estimated from changes in soil water storage and the SIMDualKc model. As expected, K_{cb} values were very similar between the different crop stages and increased with the increase of tree density, i.e., with higher f_c and h values. In Darouich et al. [20], the relationship between the K_{cb} and f_c and h had already been revealed, with 10–14-year-old citrus and lower f_c and h values returning lower K_{cb} values than 18–20-year-old trees having larger f_c and h values. The K_{cb} values also changed with climate scenarios, from low to very high evapotranspiration demand, namely considering the inverse relation between $K_{cb\ full}$ and RH_{min} (Equation (4)). The K_{cb} values for scenarios with a high-climate and very high climate demand were in close agreement with those tabulated in Pereira et al. [19] and obtained using the A&P approach. For low- and medium-climate demand scenarios, the estimated K_{cb} values in Table 4 were inferior to the tabulated ones in Pereira et al. [19].

The K_{cb} estimates for low-density orchards agreed with those for orange in Vilallobos et al. [56], for which an f_c of 0.42 corresponded to $K_{cb\ mid}$ = 0.58; and with El-Raki et al. [57], for which an f_c of 0.30 corresponded to $K_{cb\ mid}$ = 0.50. They were higher than those for orange, clementine, and mandarin in Ramos et al. [58] because of the lower tree height in these orchards with 5–6-year-old trees. Inversely, they were lower than those for clementine in Ballester et al. [59], for which an f_c of 0.38 resulted in a $K_{cb\ mid}$ = 0.65. Generally, the present results agreed with those reported by Pereira et al. [22]. The same happened with the medium-density orchards, for which the estimated K_{cb} values corresponded with those for clementine in Maestre-Valero et al. [60], with f_c = 0.66 and a $K_{cb\ mid}$ ranging from 0.50 to 0.65; and for orange reported by Taylor et al. [61], with an f_c from 0.60 to 0.63 and a $K_{cb\ mid}$ from 0.55 to 0.65. Relative to the K_{cb} estimates for high-density orchards, the values also agreed with those for lemon in Rosa [29], with f_c = 0.75 and K_{cb} = 0.67 for the mid- and end-season; and for orange in Taylor et al. [60], Peddinti and Kambhammettu [39], Jamshidi et al. [62], and Jafari et al. [63], with the f_c in orchards ranging from 0.70 to 0.88 and the $K_{cb\ mid}$ from 0.70 to 0.85.

The K_c values in Table 4 showed similar dynamics as those already reported in Darouich et al. [20], i.e., lower values during the dry irrigation season because of the small wetted area below drippers, and higher values during the rainy season when the entire soil surface was wetted and subjected to soil evaporation. Again, the reported K_c values find agreement with several studies performed in Mediterranean citrus orchards [57,64,65], as well as with those now reported by Pereira et al. [22]. As such, the K_{cb} and K_c values in Table 4 are found to be adequate for estimating the water requirements of Syrian citrus orchards.

3.2. Consumptive Use

The consumptive use of citrus species in G1 (clementine and mandarin), G2 (sweet orange), and G3 (lemon and lime) for climate scenarios of low, average, high, and very high demand and for the water-saving/deficit-irrigation scenarios relative to the threshold MAD of 1.05, 1.10, 1.20, and 1.30 is presented in Tables 5–7.

Table 5. Season potential and actual crop evapotranspiration and transpiration (mm) for G1 crops (clementine and mandarin) under various scenarios of plant density, climate demand, and deficit-irrigation MAD * thresholds.

Plant-Density Scenarios	Climate-Demand Scenarios	ET_c (mm)	T_c (mm)	MAD Irrigation Thresholds							
				1.05		1.10		1.20		1.30	
				$ET_{c\ act}$	$T_{c\ act}$	$ET_{c\ act}$	$T_{c\ act}$	$ET_{c\ act}$	$T_{c\ act}$	$ET_{c\ act}$	$T_{c\ act}$
Low	Low	869	579	856	561	841	547	809	520	778	493
	Average	939	614	927	597	911	583	880	556	847	528
	High	959	648	939	624	920	605	879	570	838	533
	Very high	1229	813	1203	782	1175	757	1124	710	1074	665
Med, small tree	Low	815	609	800	591	785	577	754	549	724	523
	Average	878	655	863	637	850	625	819	597	789	570
	High	902	682	880	657	861	639	822	603	781	565
	Very high	1157	864	1126	829	1100	805	1050	758	997	709
Med, tall tree	Low	863	658	846	637	829	622	795	590	762	560
	Average	929	705	912	684	896	670	863	640	829	609
	High	963	743	938	714	916	693	872	652	826	610
	Very high	1234	940	1200	902	1170	874	1112	820	1055	766
High, small tree	Low	900	712	879	689	860	671	823	636	786	603
	Average	955	753	936	731	918	714	881	680	844	646
	High	996	795	967	763	943	740	896	696	850	652
	Very high	1265	998	1223	952	1195	926	1134	869	1074	811
High, tall tree	Low	1100	926	1078	902	1054	879	1000	827	952	781
	Average	1171	982	1149	957	1119	929	1072	884	1017	832
	High	1235	1041	1205	1009	1171	975	1107	914	1039	848
	Very high	1562	1310	1517	1263	1475	1221	1396	1144	1309	1061

* ET_c and $ET_{c\ act}$ are potential and actual crop evapotranspiration, respectively; T_c and $T_{c\ act}$ are potential and actual crop transpiration, respectively; MAD, management-allowed deficit.

Table 6. Season potential and actual crop evapotranspiration and transpiration (mm) for G2 crops (orange) under various scenarios of plant density, climate demand, and deficit-irrigation MAD * thresholds.

Plant-Density Scenarios	Climate-Demand Scenarios	ET_c (mm)	T_c (mm)	MAD Irrigation Thresholds							
				1.05		1.10		1.20		1.30	
				$ET_{c\ act}$	$T_{c\ act}$	$ET_{c\ act}$	$T_{c\ act}$	$ET_{c\ act}$	$T_{c\ act}$	$ET_{c\ act}$	$T_{c\ act}$
Low	Low	869	579	856	560	841	547	809	520	778	493
	Average	938	613	925	595	910	582	878	555	846	528
	High	953	644	933	619	915	603	873	566	833	531
	Very high	1227	812	1199	778	1175	757	1122	709	1072	663
Med, small tree	Low	826	619	811	601	795	586	763	558	733	531
	Average	878	655	863	637	850	625	819	597	789	570
	High	898	679	877	655	858	636	818	600	779	564
	Very high	1157	864	1126	829	1100	805	1050	758	997	709
Med, tall tree	Low	874	668	857	647	838	631	805	599	771	569
	Average	927	703	910	683	894	667	859	637	827	607
	High	961	741	936	713	913	692	869	650	825	609
	Very high	1235	940	1199	900	1171	875	1114	820	1057	767
High, small tree	Low	903	715	882	691	863	673	826	639	788	604
	Average	965	762	943	738	926	722	889	688	853	654
	High	991	790	962	759	939	736	892	692	845	648
	Very high	1278	1011	1233	963	1206	938	1145	878	1083	819
High, tall tree	Low	1103	928	1078	901	1057	882	1004	831	952	780
	Average	1170	981	1149	956	1119	928	1068	880	1017	831
	High	1221	1027	1192	995	1157	961	1093	899	1027	836
	Very high	1573	1322	1527	1272	1486	1233	1401	1152	1317	1069

* ET_c and $ET_{c\ act}$ are potential and actual crop evapotranspiration, respectively; T_c and $T_{c\ act}$ are potential and actual crop transpiration, respectively; MAD, management-allowed deficit.

Table 7. Season potential and actual crop evapotranspiration and transpiration (mm) for G3 crops (lemon and limes) under various scenarios of plant density, climate demand, and deficit-irrigation MAD * thresholds.

Plant-Density Scenarios	Climate-Demand Scenarios	ET_c (mm)	T_c (mm)	MAD Irrigation Thresholds							
				1.05		1.10		1.20		1.30	
				$ET_{c\ act}$	$T_{c\ act}$	$ET_{c\ act}$	$T_{c\ act}$	$ET_{c\ act}$	$T_{c\ act}$	$ET_{c\ act}$	$T_{c\ act}$
Low	Low	867	576	854	558	838	545	807	518	776	491
	Average	938	613	926	595	910	581	880	555	846	527
	High	956	646	937	622	917	603	876	568	836	532
	Very high	1225	809	1198	777	1173	754	1122	707	1070	661
Med, small tree	Low	820	614	806	596	789	581	759	554	727	526
	Average	878	655	863	637	850	625	819	597	789	570
	High	909	689	887	664	867	645	827	609	787	571
	Very high	1147	855	1118	822	1094	799	1041	750	990	703
Med, tall tree	Low	871	666	854	644	836	628	802	597	767	566
	Average	927	703	909	682	893	667	859	636	827	607
	High	962	741	936	713	915	693	870	651	826	610
	Very high	1222	928	1187	889	1162	865	1104	811	1047	758
High, small tree	Low	899	711	878	687	859	670	822	635	786	602
	Average	965	762	943	738	926	722	889	688	853	654
	High	1002	801	973	769	949	745	901	700	854	656
	Very high	1264	997	1222	951	1194	925	1134	868	1073	810
High, tall tree	Low	1101	926	1078	900	1054	877	1003	829	951	779
	Average	1178	989	1155	963	1128	938	1074	886	1021	836
	High	1231	1038	1199	1002	1164	969	1102	909	1035	845
	Very high	1549	1294	1504	1247	1463	1207	1382	1128	1302	1051

* ET_c and $ET_{c\ act}$ are potential and actual crop evapotranspiration, respectively; T_c and $T_{c\ act}$ are potential and actual crop transpiration, respectively; MAD, management-allowed deficit.

The consumptive use represents the water taken up by plants in the evapotranspiration process (use) and that evaporated from the soil and transpired by the plants, i.e., water that is not reusable. Because K_c values were assumed to be the same among citrus species (Table 4), as with FAO56 and in Rallo et al. [15], the potential consumptive use of citrus trees ended quite similarly among all the groups, i.e., G1, G2, and G3, with minor differences resulting from different dates and lengths of the crop-growth stages (Table 2).

The most important factors affecting the potential consumptive use (ET_c) were the density of trees in the citrus orchards and the tree heights. The larger the trees' canopy, the greater the consumptive use, resulting also in higher K_{cb} values being estimated with the A&P approach. Large differences were naturally found among climate scenarios, with seasonal ET_c values ranging from 867 mm under low demand to 1573 mm under very high climatic demand. The beneficial water use, i.e., the T_c component, represented 65.4% to 84.3% of the total consumption use and was higher for the climate scenarios of very high demand because the transpiration surface of trees was larger then, while the evaporative soil surface (f_{ew}) was smaller since it was reduced to the exposed area wetted by drippers.

Darouich et al. [20] have already shown that drip irrigation could reduce the non-beneficial use of water, i.e., the E_s component, when compared with other irrigation methods (bubblers, micro-sprinkler, and ring basin). Jovanovic et al. [66] listed several other strategies to further reduce the non-beneficial use of water in orchard systems, mainly deficit-irrigation strategies. Figure 3 presents the consumption-use savings (ET_c–$ET_{c\ act}$) in G1, G2, and G3, resulting from deficit irrigation. The consumption-use savings increased with climate demand and with deficit irrigation because less water was applied, thus reducing the $ET_{c\ act}$ values. Naturally, such strategies impacted yields, as discussed in Section 3.4.

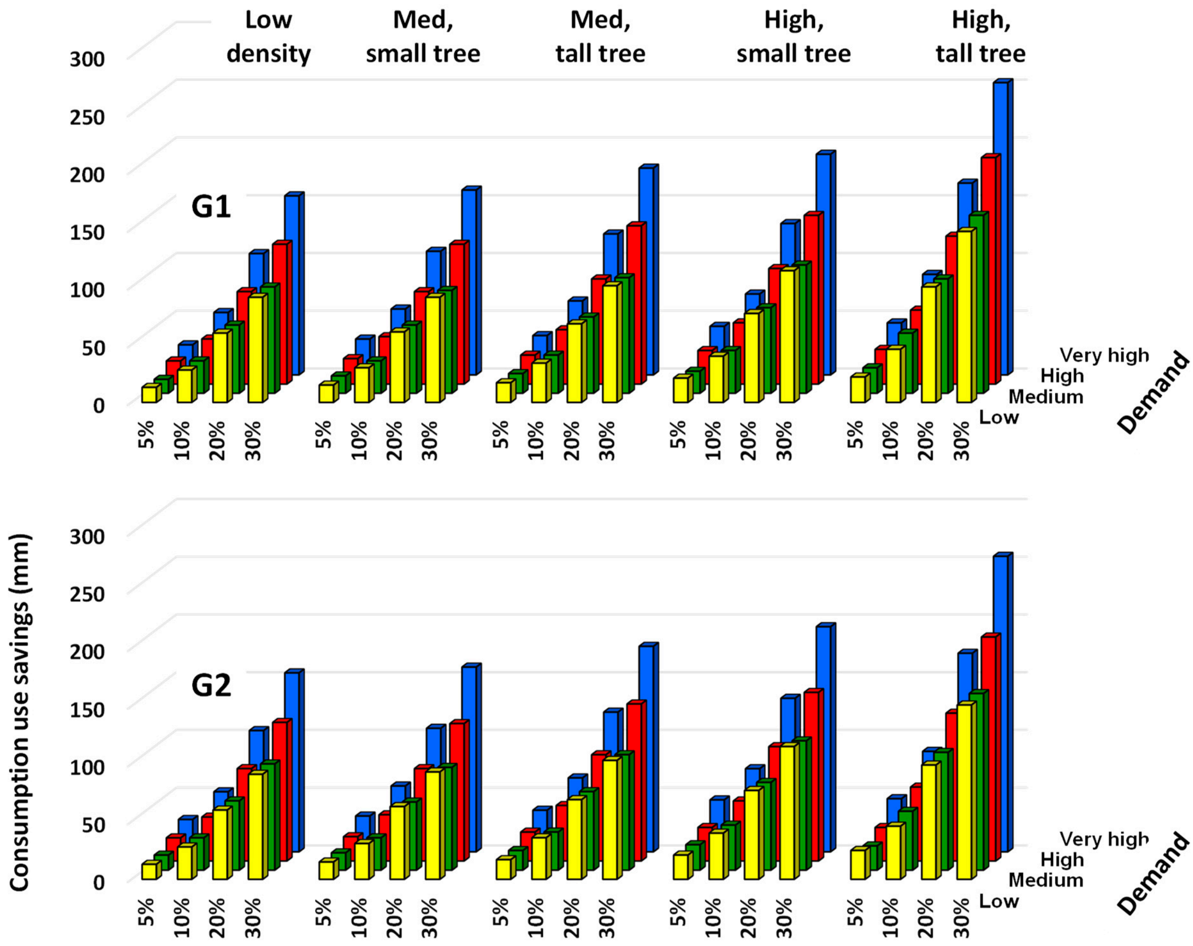

Figure 3. *Cont.*

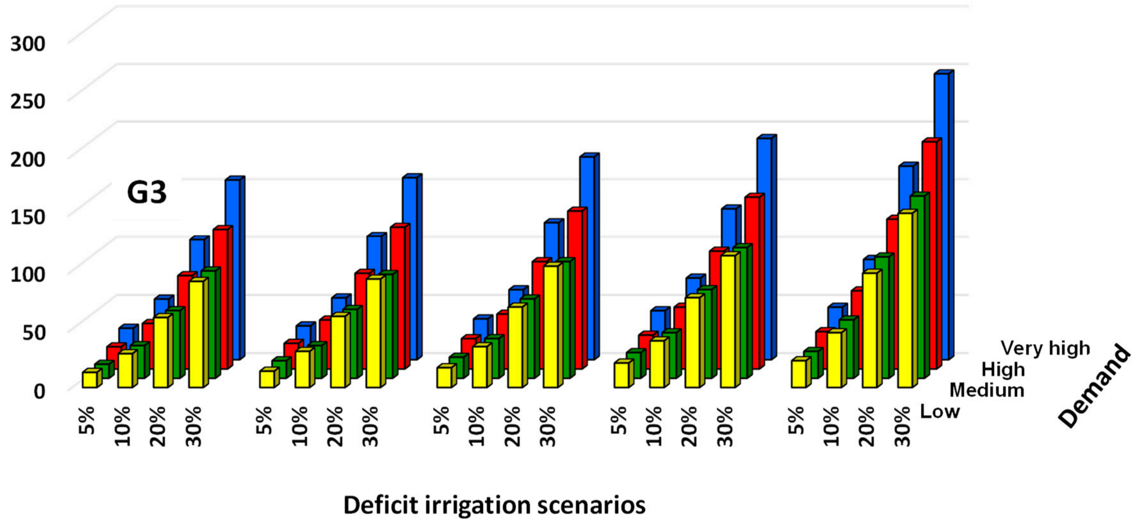

Figure 3. Consumptive-use savings in G1 (clementine and mandarin), G2 (orange), and G3 (lemon and lime) under different scenarios of tree density, climate demand, and deficit irrigation.

3.3. Gross Irrigation Water Savings

Figure 4 presents the gross irrigation water savings in G1, G2, and G3, considering an irrigation efficiency of drip systems of 85% [67]. A full irrigation schedule was considered to be the baseline to quantify water savings in each deficit-irrigation scenario. This full irrigation schedule aimed to maintain soil moisture levels close to the RAW, without the crop entering stress. Therefore, the values shown in Figure 4 represent a minimum threshold of possible savings because substantially higher values would be obtained if the target of the full irrigation schedule was to maintain soil moisture closer to the soil field capacity.

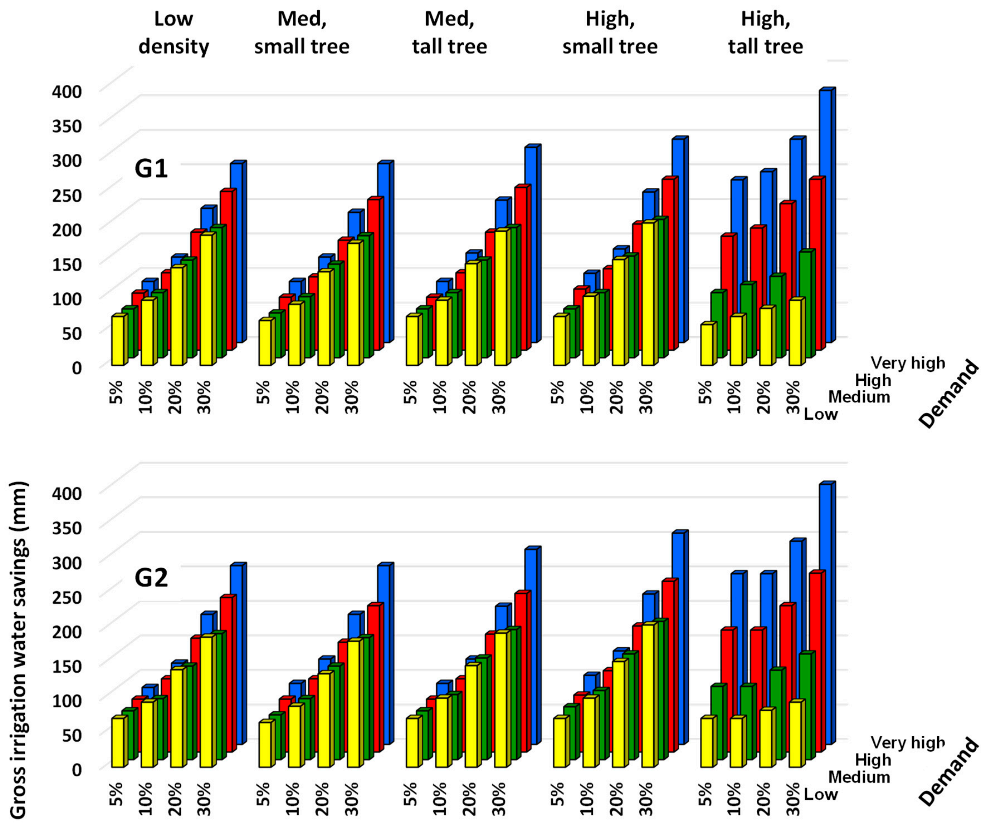

Figure 4. *Cont.*

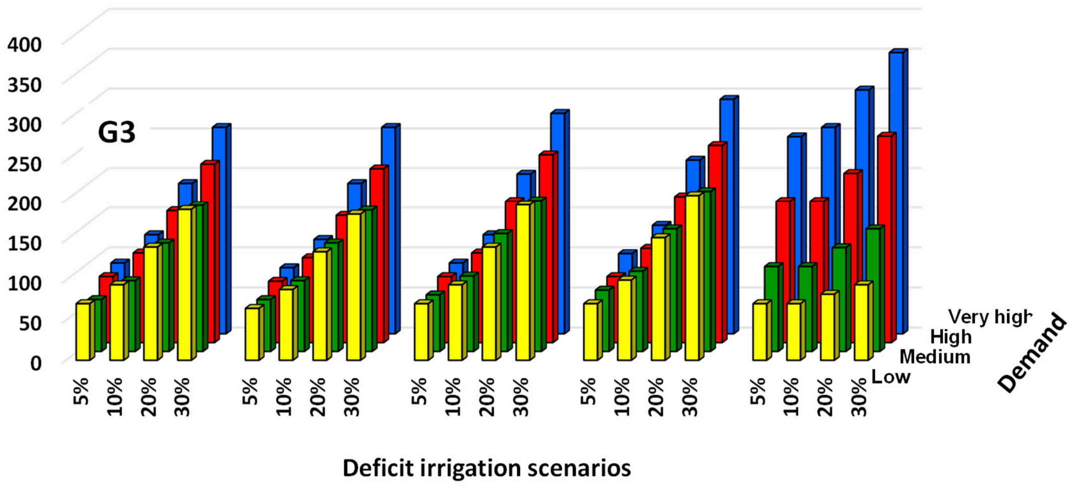

Figure 4. Gross irrigation water savings in G1 (clementine and mandarin), G2 (orange), and G3 (lemon and lime) under scenarios of different climate demand and deficit irrigation.

Estimated gross (and net) crop irrigation requirements (CIRs) found a general correspondence with values in the literature, particularly when deficit-irrigation strategies were considered [58,68,69]. In all groups, the CIR increased with plant density and atmospheric demand. Additional water was needed to maintain soil moisture conditions within the proposed trigger and target thresholds of each irrigation strategy. Water savings followed the same trend, with higher values also found with increasing planting density and climate demand. Still, the most important factor contributing to saving water was deficit irrigation. This resulted in substantial savings of water, which ranged from 65 mm (low-density orchards under low demand) to 376 mm (high-density orchards and very high demand). The higher the imposed stress, the lower the amount of irrigation water applied and the larger the water saving when compared with the full irrigation schedule.

3.4. Expected Yield Decline

The expected yield declines due to the estimated deficits produced for water saving are presented in Tables 8–10 for G1, G2, and G3 crops. Yield reductions were similar in G1 and G2. G3 showed more contrasting differences due to the greater tolerance of lemon and lime to water stress.

Table 8. Expected yield decline (YD) versus water saving (WS) for G1 (clementine and mandarin) under deficit-irrigation (management-allowed deficit, MAD: 1.05, 1.10, 1.20, and 1.30) and climate (low, medium, high, and very high demand) scenarios.

Plant Density	Climatic Demand	Deficit-Irrigation Strategies							
		MAD = 1.05		MAD = 1.10		MAD = 1.20		MAD = 1.30	
		WS (%)	YD (%)	WS (%)	YD (%)	WS (%)	YD (%)	WS (%)	YD (%)
Low	Low	14	7	18	12	28	26	37	42
	Average	14	6	19	11	28	24	38	38
	High	12	7	17	14	26	29	35	47
	Very high	11	8	15	15	24	30	31	50
Med, small tree	Low	13	6	18	12	28	25	37	42
	Average	14	6	19	11	29	22	38	35
	High	12	7	17	14	25	28	35	46
	Very high	11	8	16	15	24	30	33	49

Table 8. *Cont.*

Plant Density	Climatic Demand	Deficit-Irrigation Strategies							
		MAD = 1.05		MAD = 1.10		MAD = 1.20		MAD = 1.30	
		WS (%)	YD (%)	WS (%)	YD (%)	WS (%)	YD (%)	WS (%)	YD (%)
Med, tall tree	Low	13	6	18	12	28	25	37	42
	Average	14	7	19	12	28	24	37	38
	High	11	8	16	14	25	29	34	48
	Very high	10	8	15	15	24	30	33	50
High, small tree	Low	12	7	18	12	27	26	36	42
	Average	13	7	18	12	27	25	37	40
	High	12	8	16	14	25	29	34	48
	Very high	11	9	15	15	24	30	33	50
High, tall tree	Low	8	5	13	10	22	23	31	38
	Average	9	5	14	12	23	25	33	43
	High	9	6	12	12	22	25	30	44
	Very high	8	7	13	13	21	27	31	45

Table 9. Expected yield decline (YD) versus water saving (WS) for G2 (orange) under deficit-irrigation (management allowed deficit, MAD: 1.05, 1.10, 1.20, and 1.30) and climate (low, medium, high, and very high demand) scenarios.

Plant Density	Demand	Deficit-Irrigation Strategies							
		5%		10%		20%		30%	
		WS (%)	YD (%)	WS (%)	YD (%)	WS (%)	YD (%)	WS (%)	YD (%)
Low	Low	14	7	18	12	28	26	37	42
	Average	14	6	18	12	27	24	37	38
	High	12	8	16	14	25	29	34	46
	Very high	10	9	14	14	23	30	32	49
Med, small tree	Low	13	6	18	11	27	22	37	35
	Average	14	6	19	11	29	23	38	37
	High	12	6	17	12	26	25	34	41
	Very high	11	8	16	14	24	29	33	48
Med, tall tree	Low	13	6	18	11	27	22	36	36
	Average	14	6	19	12	29	25	37	40
	High	11	7	16	12	25	25	34	42
	Very high	10	8	14	14	23	29	33	48
High, small tree	Low	12	6	18	11	27	22	36	36
	Average	14	7	18	12	28	25	37	41
	High	11	7	16	12	25	25	34	42
	Very high	11	9	15	14	24	30	34	49
High, tall tree	Low	9	5	14	8	23	20	32	33
	Average	9	5	14	11	23	23	33	38
	High	9	5	14	11	22	23	31	39
	Very high	8	6	13	12	23	22	31	45

Plant density and atmospheric demand had little influence on relative yields. On the other hand, the greater the water deficit condition imposed by the irrigation strategy, the greater the yield reduction. Considering that some of the estimated yield reduction, namely for irrigation deficit scenarios of 20% and 30%, represent a significant impact on farmers' income and profitability, an economic analysis needs to be performed to complement the viability of those strategies. Still, results need also to be interpreted in a context of increasing scarcity that requires the implementation of policy measures to help mitigate farmers' losses.

Table 10. Expected yield decline (YD) versus water saving (WS) for G3 (lemon and limes) under deficit-irrigation (management allowed deficit, MAD: 1.05, 1.10, 1.20, and 1.30) and climate (low, medium, high, and very high demand) scenarios.

Plant Density	Demand	Deficit-Irrigation Strategies							
		5%		10%		20%		30%	
		WS (%)	YD (%)	WS (%)	YD (%)	WS (%)	YD (%)	WS (%)	YD (%)
Low	Low	14	6	18	11	28	23	37	39
	Average	13	5	18	10	27	19	37	30
	High	13	7	17	12	25	24	34	40
	Very high	11	6	15	12	23	24	32	38
Med, small tree	Low	13	6	18	11	28	23	37	38
	Average	14	5	19	9	29	18	38	28
	High	12	7	17	12	25	24	35	39
	Very high	11	6	15	11	24	23	33	37
Med, tall tree	Low	13	6	18	11	26	24	36	39
	Average	14	5	19	10	29	19	37	30
	High	12	7	16	12	26	24	34	40
	Very high	10	7	15	12	24	24	33	39
High, small tree	Low	12	6	18	11	27	24	36	40
	Average	14	6	18	10	28	20	37	32
	High	11	7	16	12	25	24	34	41
	Very high	11	8	15	12	24	25	33	40
High, tall tree	Low	9	5	14	9	23	21	32	36
	Average	9	5	14	10	23	21	34	35
	High	9	5	13	11	22	22	32	37
	Very high	8	6	13	11	24	22	30	37

3.5. Improving Water Management of Citrus Orchards in Coastal Syria

The citrus sector in Syria is slowly recovering from years of civil war and embargo to economic trade. Once one of the most important sources of income in the agricultural sector, Syrian growers face enormous challenges today because of the economic crisis and limits to exportations that have caused the drop of fruit prices and increased costs of inputs such as fertilizers. At the same time, drought and increasing temperatures have built up a larger pressure on water resources, stressing the need for improved management.

This study contributes the necessary information for improving irrigation water management in Syrian citrus orchards in order to build a software platform to progressively implement farmers' advice on the most adequate water savings, presently the best MAD irrigation scheduling thresholds. This can not only contribute to reducing water withdrawals in the region by improving crop water use and irrigation efficiency but also by increasing water and land productivity and further minimizing nutrient leaching from agricultural plots. On the one hand, K_{cb} and K_c values are provided to be efficiently used in irrigation management (Table 4), allowing us to accurately estimate crop water requirements in orchards with different planting densities and under different climate-demand conditions. On the other hand, MAD thresholds for the consumptive use of citrus trees and respective irrigation requirements are defined by considering the planting densities and climate conditions, as well as the deficit-irrigation/yield-decrease options. These deficit-irrigation strategies, which consisted of adopting an increased MAD of 1.05, 1.10, 1.20, and 1.30 p, shall be optimized when yield values will not be submitted to the war pressure and when production costs result from an open market and water costs will reflect an agricultural policy and not a war policy. Nevertheless, the implementation of this methodology is appropriate to help build an information platform and to help farmers improve their crop water use under scarcity.

The seasonal consumptive use of the different citrus species considered in the analysis ranged from 867 to 869 mm in orchards of low planting density under low demand and from 1549 to 1573 mm in orchards of very high planting density under very high climatic demand (Tables 5–7). In a full irrigation schedule, about 44% (425 mm) to 66% (820 mm) of the seasonal consumption use is likely to be met by irrigation. The estimated values are comparable to those in the literature, although the highest are not commonly observed in the region, and we hope that they will not be often achieved. The related gross irrigation requirements were estimated to be 15% higher than those net estimates, representing substantial water extractions that may not be available in a context of increasing scarcity. For this reason, several deficit-irrigation strategies were evaluated to reduce the seasonal consumption of water and irrigation needs of citrus orchards.

The mild deficit-irrigation strategy (MAD = 1.05 p) led to an almost nil reduction in the consumptive use of water (1–4%) but to important savings in the gross CIR (8–14%), with quite a small impact on yields (5–9% reduction). As deficit-irrigation strategies become more pronounced, $ET_{c\ act}$ may reduce by less than 10–16% (e.g., MAD = 1.10 p); thus, a small reduction in the consumptive use of water was also foreseen. However, when the gross water savings were high (30–37%), so were the impacts on yields (30–50% reduction), and their economic feasibility is then doubtful. Thus, moderate-to-high water-saving strategies may only be viable when supported by an economic analysis of the trade-offs between saved water and monetary incomes. This seems even more relevant in today's context of low prices for marketable yields. Based on this analysis, it seems reasonable to conclude that substantial water savings can only be reached when the prices of citrus fruits recover to the levels prior to the civil war and the economic crisis, and the market of goods for crop production and water application and management will not be constrained as at present.

4. Conclusions

This study has to be considered together with the one reported in a companion paper which showed a clear need for the improvement of the irrigation water management of citrus orchards in the Syrian coastal area. The current study created data required to progressively build up an information platform that offers growers' advice on the irrigation management and water saving required for the increased impacts of climate change, namely relative to higher water scarcity and higher temperature. The representative K_{cb} and K_c values for the irrigation management of citrus orchards in the region were proved, with K_{cb} values computed from representative f_c and h by using the previously validated A&P approach. The K_e values were obtained through the computation of the soil water balance, using the SIMDualKc model, which was also previously calibrated and validated in the study area, using the observed data of soil moisture dynamics collected during eight growing seasons. Both the derived K_{cb} and K_c values found correspondence with those determined in Mediterranean climate orchards with similar conditions.

The consumptive use of citrus orchards was determined on the basis of a variety of characteristics observed in the Syrian coastal area, mainly tree density and plant height. Estimates further considered the variability of climate conditions in the Syrian coastal area, with water-saving thresholds set for scenarios of low, medium, high, and very high demand. The gross irrigation water savings ranged from 65 to 376 mm, with natural impacts on yields. Relationships between water savings and expected yield declines were drawn. Estimates also considered deficit-irrigation strategies based on prospects of increasing scarcity. These information issues shall be progressively updated when the platform is installed, and research using the A&P approach and SIMDualKc shall continue to better identify the debilities that need to be focused on and also implement real-time irrigation management.

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