Estimation of Actual Water Requirements and Water Productivity of Date Palm (Phoenix dactylifera L.) cv. Barhi under the Conditions of Southern Iraq

Assim N. Al-Mansor
University of Basrah
Abdulrahman D. Alhamd
University of Basrah
Farkad M. Al-Musawi
farkad.hameed@uobasrah.edu.iq

University of Basrah

Research Article

Keywords: Date palm, Water requirements, Evapotranspiration, Crop coefficient (Kc), Water productivity (CWP), Deficit irrigation, and Bubbler irrigation system

Posted Date: November 19th, 2025

DOI: https://doi.org/10.21203/rs.3.rs-8022331/v1

Additional Declarations: No competing interests reported.

Version of Record: A version of this preprint was published at Water Conservation Science and Engineering on June 13th, 2026. See the published version at https://doi.org/10.1007/s41101-026-00531-y.

Estimation of Actual Water Requirements and Water Productivity of Date Palm (*Phoenix dactylifera* L.) cv. Barhi under the Conditions of Southern Iraq

Assim N. Al-Mansor[1], Abdulrahman D. Alhamd[2], Farkad M. Al-Musawi[1*]

1. Department of Agricultural Machines and Equipment, College of Agriculture, University of Basrah, Basrah postal code 61004, IRAQ.
2. Date Palm Research Centre- University of Basrah, Basrah postal code 61004, IRAQ.

Abstract

Date palms (Phoenix dactylifera L.) struggle in arid places due to water scarcity and rising demand. Therefore, we must find more efficient ways to water them to maintain economically viable water use. Researchers in the southern portion of Basrah Governorate (Abu Al-Khasib District) employed the bubbler irrigation method to analyze water productivity under different irrigation levels and calculate Barhi date palm water requirements in 2023 and 2024. ETO was calculated using the US Class A Pan method. We then adjusted the crop coefficient (Kc) using FAO calculations to account for local climatic parameters as wind speed, relative humidity, and plant height. T1 (45%), T2 (65%), T3 (85%), and TC (100%) irrigation levels represented varied proportions of water demand. Seasonal water application rates per tree were 99, 143, 188, and 221 m^3. Nine replications produced 36 experimental units using a randomized complete block design (RCBD). Daily ETo readings ranged from 2.86 to 13.33 mm/day, averaging 7.8 mm/day annually. Across all crops, ETc adj was 2955 mm/year, while Kc ranged from 0.77 to 1.15. Summer and winter watering frequency disturbances occurred at 5-day and 32-day intervals. Analysis of variance among irrigation settings revealed significant differences in water productivity and agricultural output. Treatment 1 had the highest water productivity (0.77 kg/m^3), followed by T3, T2, and TC (0.59, 0.54, and 0.50 kg/m^3). T3 and TC yielded the most at 110 and 111 kg/tree, respectively, with no difference. According to research, increasing irrigation water did not increase productivity correspondingly but did diminish water efficiency. Date palms in water-scarce areas can be irrigated at 45% of the total need (T1) without a yield drop, indicating that this strategy is practicable.

Keywords: Date palm, Water requirements, Evapotranspiration, Crop coefficient (Kc), Water productivity (CWP), Deficit irrigation, and Bubbler irrigation system

Introduction

As the global population expands, agricultural output must be augmented to satisfy demand. This has prompted researchers to investigate diverse approaches, such as deficit irrigation methods, soil nutrient augmentation, and water retention substances, to promote crop performance and yield (Karamollacheab et al., 2025). The date palm (Phoenix dactylifera L.) is among the most ancient fruit plants recognized by humanity, thought to have originated in the Mesopotamian area (modern-day Iraq) about 4000 B.C. (FAO and AOAD, 2023). It disseminated from this region to the Arabian Peninsula, the Near East, and North Africa before further extending to other global areas. Iraq ranks as one of the foremost date-producing nations worldwide, with an expected output of 639,315 tons grown on 213,032 hectares, as reported by FAOSTAT (2021). The cultivation of date palms, especially the Barhi type, serves as a strategic foundation in southern Iraq owing to its economic, social, and environmental importance derived from its superior quality and market value.

Notwithstanding its significance, date palm farming has increasing obstacles stemming from water shortages, elevated temperatures, and soil deterioration attributable to salt. The Middle East, especially Iraq, is one of the regions most impacted by climate change related to water shortages (Hameed et al., 2019). Sultan et al. (2023) indicated that the region's climate is shifting towards more aridity owing to reduced precipitation and heightened evapotranspiration rates, whilst Kenawy et al. (2025) underscored the pressing need for implementing appropriate adaptation methods to address these circumstances.

The date palm has moderate drought tolerance; nonetheless, extended durations of water scarcity may impede its development and output (Doorenbos & Pruitt, 1977). Therefore, there is an immediate need to develop appropriate irrigation management systems to enhance water usage efficiency (Ahmed Mohammed et al., 2020). Studies demonstrate that regular irrigation improves both produce quantity and quality, while meticulous modifications to irrigation schedules may save water and prevent harm from over- or deficit irrigation (Alihouri, 2021).

The water requirements of date palms are contingent upon several factors, including soil type, climate, tree age, and irrigation method. The FAO (2008) states that the requirements are between 150 and 350 m^3/tree in Saudi Arabia, 102 and 164 m^3/tree in Iran, 183 and 240 m^3/tree in Oman, and 130 and 173 m^3/tree in the United Arab Emirates.

In this context, water productivity (WP) serves as a superior and more precise metric for assessing water use in agriculture compared to total output (Pereira et al., 2002). The FAO (2008) reported that the water productivity of date palm farming typically ranges from 0.18 to 0.37 kg/m^3. The efficiency may be enhanced with the use of contemporary irrigation and agricultural techniques (Al-Mulla et al., 2017). Al Hinai and Jayasuriya (2021) stated that enhancing water usage efficiency increases product value and prolongs the sustainability of agricultural systems in arid regions.

To design sustainable irrigation plans, it is essential to establish the water requirements of date palms. This depends on understanding the components of reference evapotranspiration (ETo) and its local climatic inputs. To get the actual evapotranspiration (ETc), one typically multiplies the reference evapotranspiration (ETo) by the crop coefficient (Kc). The Kc is modified for severe settings according to local variables such as wind velocity, relative humidity, and vegetation height (Allen et al., 1998). The mean ETo in Jordan was 1920 mm, while the Kc values during the growing season varied from 0.5 to 1.18 (Mazahrih et al., 2012). In the UAE, Kc values ranged from 0.60 in winter to 1.18 in summer, and "Lulu" date palms required around 140 liters of water daily per tree (Al-Muaini et al., 2019).

Annual water demands vary depending on geography, according to FAO (2008), annual water requirements vary across geographic locations, ranging from 1500–3500 mm in Algeria, 2700–3600 mm in the United States, 2230 mm in Egypt, While it ranged between 2500-3200 mm in Iraq. Abdul Salam and Al Mazrouei (2006) estimated the reference annual evapotranspiration in Kuwait at 2883 mm and the actual at 2685 mm, with monthly variations from 74 mm in January to 392 mm in June. AI-Baker (1972) indicated that the annual requirement ranged from 115–306 m^3/palm tree, while Alamoud et al. (2012) indicated that the actual consumption of date palms in Saudi Arabia ranged from 59.4 to 80 m^3/palm tree/season. In an older study, the average annual water consumption of date palms in the Riyadh region was approximately 2396 mm (Al-Amoud et al., 2000). Al-Omran et al.'s stud (2019) showed that ETc rates ranged from 1837.76 to 2418.75 mm/year in different locations in Saudi Arabia.

The results of Ismail et al. (2014) showed that the 50% ETc irrigation treatment achieved the highest irrigation efficiency, but it was not economically viable due to reduced yield. Another experiment showed that the 75% ETc treatment recorded the highest significant differences ($P \leq 0.05$) in water productivity, while the 100% ETc treatment yielded the highest quantitative productivity, indicating the possibility of reducing irrigation water without significantly impacting yield. This study recommended irrigating palm trees with 75% ETc to ensure water use efficiency while maintaining yield quality and quantity. Several studies also confirm the importance of deficit irrigation in improving water use efficiency, provided that sufficient moisture is maintained throughout the season (Geerts and Raes, 2009). Mazen et al. (2018) recorded a decrease in productivity when irrigation was reduced to 85%, 75%, and 65% of ETc, with reductions of 181.5%, 168%, 172%, and 169%, respectively, under a bubbler irrigation system.

Based on the above, this study aims to estimate the actual water requirements of date palm (Phoenix dactylifera L.) cv. Barhi under the prevailing climatic conditions of southern Iraq through the following objectives:

1. Estimating the reference evapotranspiration (ETo) using local climatic data and the U.S. Class A pan evaporation method.

2. Adjusting the crop coefficient (Kc) based on the FAO equation and local climatic factors.
3. Calculating the adjusted actual evapotranspiration (ETc adj) and developing an irrigation scheduling program accordingly.
4. Evaluating the effects of different irrigation levels on yield performance and crop water productivity (CWP).

Materials and Methods:

Study Site and Climatic Conditions

The research was carried out in Abu Al-Khaseeb District - Basra Governorate, southern Iraq, located at latitude 30° 27' 19.0 north and longitude 47° 58' 45.0" east at an altitude of 1 m above sea level. This region is characterized by a hot and dry climate, with temperatures exceeding 50°C in the summer in a soil with a clay texture. The experiment was conducted during two consecutive seasons 2023 and 2024. Table 1 shows some of the initial physical properties of the soil.

Table 1: Initial physical properties of soil

Soil Depth	Texture	Soil particle distribution %			F.C.%	P.W.P.%	B.d.
cm		Sand	Silt	Clay	θ at33 kPa	θ at 1500 kPa	g cm^{-3}
0-30	Silty clay loam	11.435	49.015	39.55	41.04	22.88	1.36
30-60	Silty clay loam	10.28	51.17	38.55	41.59	22.95	1.38
60-90	Silty clay loam	11.25	51.17	37.58	42.23	22.94	1.39
90-120	Silty clay loam	10.42	52.33	37.25	42.86	23.52	1.38

Experimental Design and Treatment Arrangement

The experiment was conducted using a randomized complete block design (RCBD) with four irrigation levels (IRRLEVEL 1-4). It was replicated over nine blocks, yielding 36 experimental plots. This strategy was used to address possible geographical variability within the field and to enhance the precision of treatment comparisons. The field experiment was performed on 36 palm palms designated as experimental units. These were chosen as 15-year-old date-producing trees exhibiting a high level of uniformity regarding vegetative development, size, and age of the Barhi variety. The palms were positioned 8 meters apart in both directions. The irrigation network was established with a bubbler technology. Subsequent horticultural upkeep was performed on the palm plants, standardizing the number of clusters across all treatments to eight clusters per palm for the 2023 and 2024 seasons.

Irrigation System and Treatment Levels

The bubbler irrigation system was administered at four irrigation levels, each representing a different proportion of the total water requirement:

TC (Control) = 100% of water requirement
T3 = 85% of water requirement
T2 = 65% of water requirement
T1 = 45% of water requirement

The treatments produced seasonal irrigation volumes of 221, 188, 143, and 99 m^3 per tree, respectively.

Calculation of Water Requirements of Date Palm

Reference Evapotranspiration (ETo)

Daily evaporation was quantified with a U.S. Class A evaporation pan positioned in an unobstructed location next to the experimental site. Reference evapotranspiration (ETo) was determined using the following equation:

$$\ldots\ldots\ldots\ldots (1) ETo = Kp \times Epan$$

Where:

ETo = reference evapotranspiration (mm/day),

Epan = measured evaporation from the pan (mm/day),

Kp = pan coefficient, taken as 0.75.

Crop Evapotranspiration (ETc)

Crop evapotranspiration (ETc) was determined using the equation:

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2) ETc = ETo \times Kc$$

Where:

ETc = crop evapotranspiration (mm/day),

ETo = reference evapotranspiration (mm/day),

Kc = Crop Coefficient. The crop coefficient for palm trees varies between 0.9 and 0.95, contingent upon the growth season, as stated in FAO report 56. The crop coefficient was modified in accordance with equation 4. Allen et al. (1998) said that the conventional crop coefficient for fruit trees must be modified in accordance with wind velocity and relative humidity under harsh climatic conditions.

Adjustment of Crop Coefficient (Kc adj)

The standard crop coefficient (Kc) for date palms was derived using the data presented in Table 2 of the Food and Agriculture Organization of the United Nations publication (Zaid, 2024), serving as the foundation for determining the reference water needs for date palms in this research. The modification was based on the findings of Allen et al. (1998) in FAO publication 56, including wind conditions, humidity, and plant height using the following equation:

$$Kc\ adj = Kc(Tab) + [0.04(u2 - 2) - 0.004(RHmin - 45)](\frac{h}{3})\text{^}0.3 \ldots\ldots(3)$$

Where:

u_2 = average daily wind speed (m/s) at 1 m height ($1 \leq u_2 \leq 6$ m/s),

$RHmin$ = minimum daily relative humidity (%), (20 % ≤ RHmin ≤ 80 %)

h = average crop height (m) during the growth stage. (0.1 m < h < 10 m)

Table 2 The standard FAO-156 crop parameters for date palms.

Growth stage	Crop name: DATEPALM					
		Init	Devel	Mid	Late	Total
Length	days	150	35	150	30	365
Crop coefficient	coeff.	0.8	0.80-1.00	1	0.8	
Rooting depth	meter	2	2	2	2	
Depletion level	fraction	0.5	0.5	0.5	0.5	
Yield response factor	coeff.	0.8	0.8	0.8	0.8	0.8

Water Requirement (WR)

Daily water requirement (WR) was determined using:

$$\ldots\ldots\ldots\ldots\ldots(4)\; WR = ETc - (Pe + Ge)$$

Where:

WR = water requirement (mm/day),

ETc = crop evapotranspiration (mm/day),

Pe = effective rainfall (mm/day),

Ge = contribution from groundwater (mm/day), assumed to be 0.

Shaded Area per Tree (Se)

The actual shaded area for each tree (*Se*) was calculated following formula: Al-Omran (2022):

$$Se = \pi r^2 \quad \ldots\ldots\ldots\ldots(5)$$

Where:

Se = Shaded area of palm tree (m^2)

r = crown radius (m).

Leaching Requirements (LR)

The minimal water volume necessary to leach accumulated salts from the root zone was calculated using the following leaching equation (Ayers & Westcot, 1985):

$$LR = \frac{Eciw}{5\,Ece - Eciw} \qquad \ldots\ldots\ldots\ldots\ldots(6)$$

Where:

LR = leaching requirement,

ECe = electrical conductivity of the saturated soil paste (dS/m) at 25°C,

Gross Water Requirements (GWR)

Total irrigation water was determined using the following formula:

$$\text{.................(7)GWR} = \frac{WR*Se}{(1-LR)*Effir}$$

Where:

GWR = gross water requirement (L/day),

WR = water requirement (mm/day),

Se = shaded area (m^2),

$Effir$ = irrigation efficiency (85% for bubbler system),

LR = leaching requirement (%).

A detailed irrigation schedule was developed for both seasons, specifying operation times and irrigation dates using two bubblers per palm with a total discharge rate of 500 L/h per tree.

Total Available Water (TAW)

Total available water (TAW) indicates the whole amount of soil moisture that may be retained within the effective root zone and used by the plant. The calculation was derived from the difference between the volumetric soil moisture content at field capacity (θFC) and the permanent wilting point (θWP) as per Allen et al. (1998):

$$\text{.................(8)}TAW = 1000\ (\theta\, FC - \theta\, WP)\ Zr$$

Where:

TAW = total available water (mm),

θFC = volumetric water content at field capacity (m^3/m^3),

θWP = volumetric water content at permanent wilting point (m^3/m^3), *Zr* = effective rooting depth (m)for palm plants. The depth is categorized into four levels based on the absorption rates at each level, since palm plants may absorb 65% to 80% of the water inside the root zone depth. (Yaaqoob,1996).

The water stored depth in the active root zone was determined using the method that proposed by Levin et al. (1979). Gravimetric assessments of soil moisture content were conducted at four depths (0–30, 30–60, 60–90, and 90–120 cm) before and after six hours subsequent to irrigation. We used an auger to obtain soil samples and determined the soil moisture content (SMC) as follows:

$$\mathrm{SMC} = (W1 - W2)\ / W2 * 100 \ldots\ldots\ldots\ldots..(9)$$

Where:

W_1 = weight of the wet soil sample (g),

W_2 = weight of the oven-dried soil sample (g), dried at 105 °C for 24 h.

The depth of water that infiltrated the root zone during irrigation was then estimated as:

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(10)\mathrm{WDZ} = (\mathrm{SMC2} - \mathrm{SMC1})\mathrm{D} * \rho * 100$$

Where:

ρ = bulk density of the soil (g/cm³),

SMC_2 = soil moisture after six hours of irrigation (%),

SMC_1 = soil moisture before irrigation (%),

D = root depth (mm).

Readily Available Water (RAW)

Readily available water (RAW) is the portion of total available water that plants may use without encountering moisture stress. The calculation was performed according to Allen et al. (1998):

$$\ldots\ldots\ldots\ldots\ldots\ldots.(11) RAW = SMD \times TAW$$

Where:

RAW: Readily Available Water in the Root Zone (mm)

SMD: Moisture Depletion Ratio, which represents 50% for palm trees, according to FAO Publication 56.

Irrigation interval (Ii)

The irrigation interval (Ii) was determined daily for each month of the year based on the Moisture Depletion Ratio (SMD) of the total available water, using the following equation:

$$\mathrm{I}i = RAW/\,WR \text{…………..}(12)$$

Where:

Ii = irrigation interval (day),

RAW = readily available water (mm),

WR = daily water requirement (mm/day).

These intervals set the duration between consecutive irrigations annually, facilitating effective scheduling in accordance with climate fluctuations and crop water requirements.

Field Measurements

Total Yield per Tree

Fruits were collected at the completely mature state. The aggregate yield of each palm was determined by weighing every gathered fruit using a field balance. The yield for each experimental unit was documented separately (kg/tree).

Water-Saving Ratio

The water-saving ratio (WS) was calculated as the percentage by dividing the differential in water consumption for a specific irrigation treatment by the total volume of water used for the whole irrigation treatment, using the following equation:

$$W.S = \frac{Fi - Dn}{Fi} * 100 \text{………………..}(13)$$

Where:

W.S = water-saving percentage (%),

Fi = total irrigation water used in the full irrigation treatment (m^3/tree/season),

Dn = total irrigation water used in the deficit-irrigation treatment (m^3/tree/season).

Crop Water Productivity (CWP)

Crop water productivity (CWP) was calculated for each experimental unit as the ratio of yield to total annual irrigation water consumed (Kambou et al., 2014), according to the following equation:

$$\mathrm{CWP} = \frac{Y}{WU} \qquad \text{............(14)}$$

Where:

CWP = crop water productivity (kg/m^3),

Y = annual yield per tree (kg),

WU = total annual irrigation water consumed for each tree (m^3).

Statistical Analysis

All data were subjected to statistical analysis with SPSS software. An analysis of variance (ANOVA) was used to assess the impacts of treatments, years, and their interactions. The importance of variations among means was evaluated using the F-test and the Revised Least Significant Difference (RLSD) at a 0.05 significance level.

Results and Discussion

Reference Evapotranspiration (ETo)

Reference evapotranspiration (ETo) is essential for determining crop water requirements and indicates the impact of climate-related factors like temperature, solar radiation, relative humidity, and wind velocity.

Figure (1) illustrates the daily reference evapotranspiration values computed by the American evaporation basin method for the research area in Abu Al-Khasib District, southern Iraq, for the 2023–2024 seasons. The readings attained an average of 2.86 and 2.89 mm day-1, respectively, in January and December, attributed to low temperatures and solar radiation. They reached their zenith in June and July (13.37 and 12.69 mm day-1, respectively), driven by the arid and elevated temperatures typical of the area in summer. The yearly daily average was 7.8 mm per day, with a total cumulative depth of ET_O amounting to 2861 mm. These results indicate a projected seasonal trend for a location characterized by a hot, arid environment, underscoring the need of precise irrigation scheduling during peak months to mitigate water stress and optimize water usage efficiency. This aligns with the findings of Alamoud et al., (2000) and Ismail et al., (2014), and AL-Omran et al., (2019) in their research on the water needs of palm trees in Saudi Arabia, indicating that ET_O is significantly elevated during arid months relative to its levels in humid months. The elevated annual ET_O value is ascribed to the significant levels of climatic factors in the research region, namely solar radiation, average temperature, and sun brightness, particularly during June, July, and August.

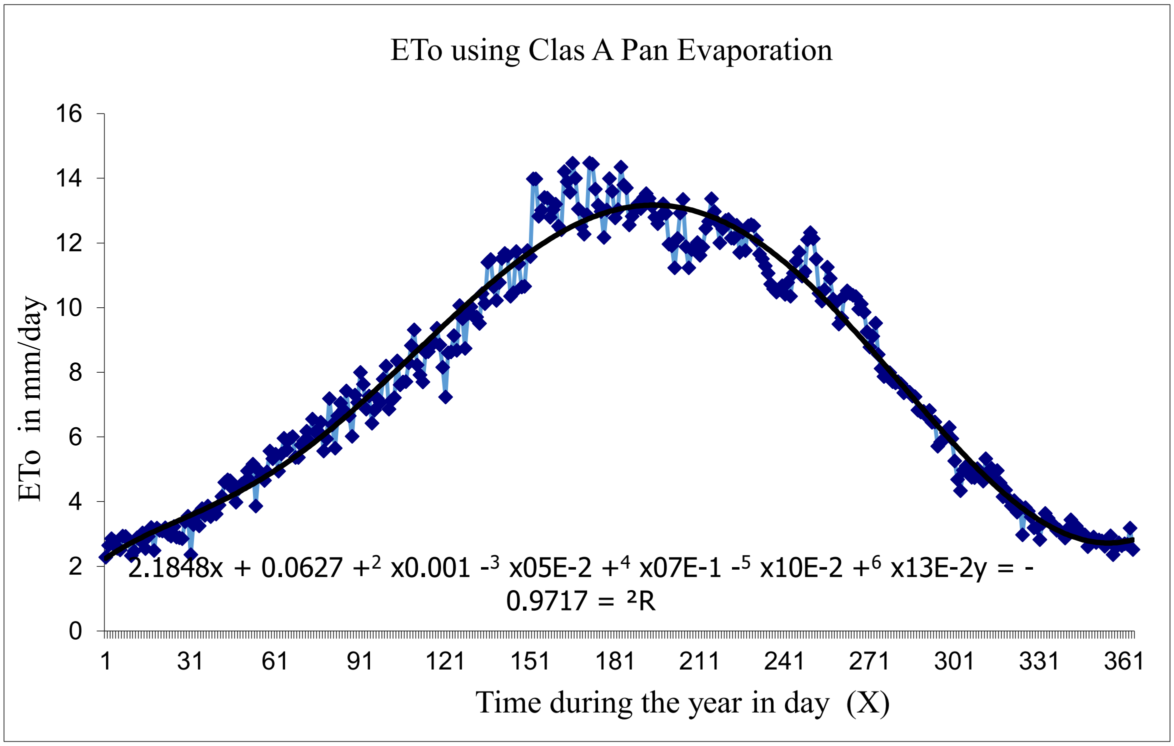

Figure 1: Daily variation in reference evapotranspiration (ETo) at the study site during the 2023–2024 seasons.

Adjusted Crop Coefficient (Kc adj)

The crop coefficient (Kc) is needed for calculating real crop water requirements (ETc), since it connects reference evapotranspiration (ETo) to actual crop water consumption. The study updated the crop coefficient to account for local environmental circumstances, using the adjustment formula proposed by the FAO (Allen et al., 1998), which considers wind speed (u_2), minimum relative humidity (RHmin), and crop height. Standard values were used for wind speed between 1.7 and 4.8 m/s, minimum relative humidity between 10.48 and 45.17%, and an average height of Barhi palm trees of 4 to 6 m (h). Consequently, the table crop coefficient was modified everyday during the whole year, as seen in Figure 2. Value oscillations are noticed throughout the day and throughout the months of the year. The distinction between the table crop coefficient (Kc_{FAO}) and the adjusted crop coefficient (K_{cadj}) is also presented. The peak values occurred in the summer months of June and July, with Kc_{FAO} attaining 1.00 and K_{cadj} reaching 1.15. Conversely, the lowest values were recorded in the winter months of December and January, where Kc_{adj} fell to 0.78 and 0.77, respectively, while Kc_{FAO} registered 0.90 for both months. Calculations indicated that the adjusted crop coefficients (Kc_{adj}) were comparatively elevated throughout the months of active growth (April–September), signifying the raised water requirement during this interval, particularly due to accelerated growth, enlarged fruit size, and increased temperatures. The phenologically stage-adjusted Kc values for Barhi palm in this research varied from 0.77 to 1.15, aligning with the ranges documented by FAO (2008) for palm growth cycles in dry regions. These data show that the palm consumes a significant quantity of water throughout its development and fruiting phases, confirming findings from other research, including Tripler et al. (2011) and Montazar et al. (2020).

Utilizing adjusted Kc enhances the precision of ETc estimates, hence augmenting irrigation efficiency and minimizing losses of water. The variation between ETo and ETc values signifies the real impact of palm plant cover and local climatic circumstances on water needs, underscoring the necessity of using precisely computed local factors instead of depending on generalized standard values.

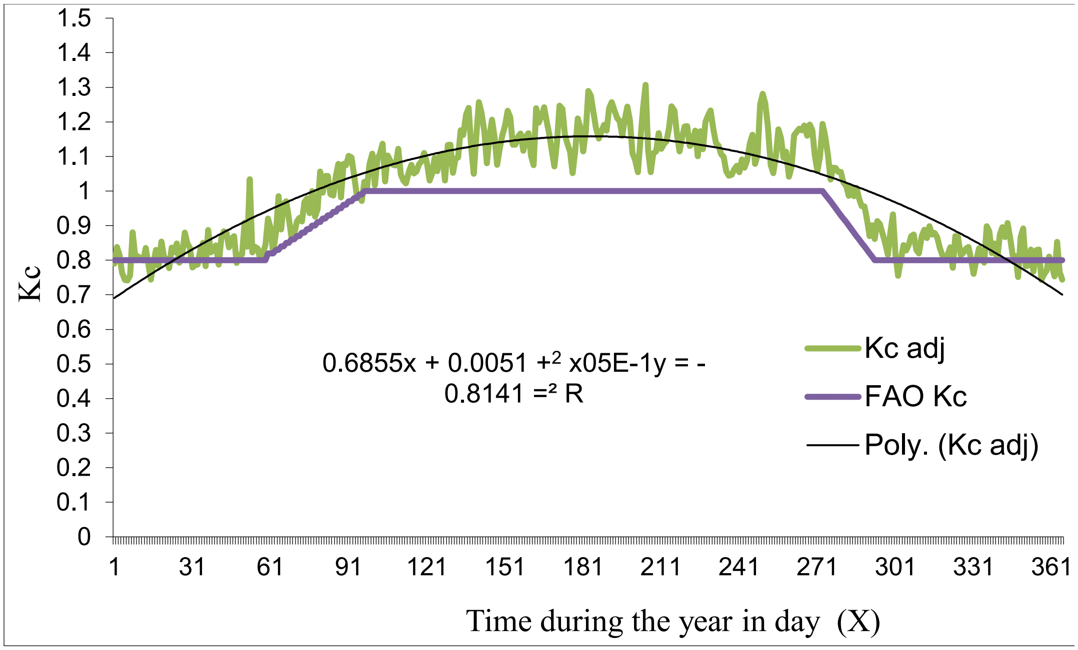

Figure 2: Table crop coefficient of the FAO publication (Kc_{FAO}), and the adjusted daily crop coefficient (Kc_{adj}).

Evapotranspiration of palm crop ET_{Ccadj}

The daily crop evapotranspiration (ET_{Cadj}) of the palm trees used in the experiment for the period from 1/1/2023 to 31/12/2024 is depicted in Figure 3. This evapotranspiration is calculated by multiplying the reference evapotranspiration (ET_O) by the adjusted crop coefficient (K_{Cadj}) in accordance with the climate elements of the study area. The data is presented for the two seasons. The ET_{Cadj} value fluctuated from 5.85 mm day-1 with a total of 190 mm in March (flowering and pollination stage) to the highest level of 15.1 and 14.6 mm day-1 in June and July, respectively, with a monthly total of 452 and 453 mm (Kimri and Khalal stage). It then decreased to 11.7 mm day-1 with a total of 351 mm in September (the end of the full maturity stage and fruit harvest). After the fruit harvest, ETc_{adj} continued to decrease, reaching the lowest values of 2.3 and 2.2 mm day-1 in December and January, with values of 71 and 69 mm, respectively. The variations in the values of both ET_O and Kc_{adj} for palm trees are the result of the varying climatic elements that occurred during the study months (temperature, sunlight, wind speed, relative humidity, evaporation, and rainfall). Consequently, the ET_{cadj} values for palm trees are also diverse. This is in agreement with the findings of Bhat et al. (2012), who conducted a study in Kuwait, where the climatic element values are in close proximity to the study area. They determined that the average ET_C values for palm trees were 407.7 mm in July, and the lowest values were 74.2 mm in January. This is also consistent with the results of a study conducted on Barhi palm trees in Iran by Alihouri (2021). Al-Omran et al. (2019) and Montazar et al. (2020) have both concluded that the water requirements of crops are mostly affected by environmental conditions. The research results indicated that the cumulative ETc values for an entire season were 2955 mm $year^{-1}$, with an average of 8.1 mm day^{-1}.

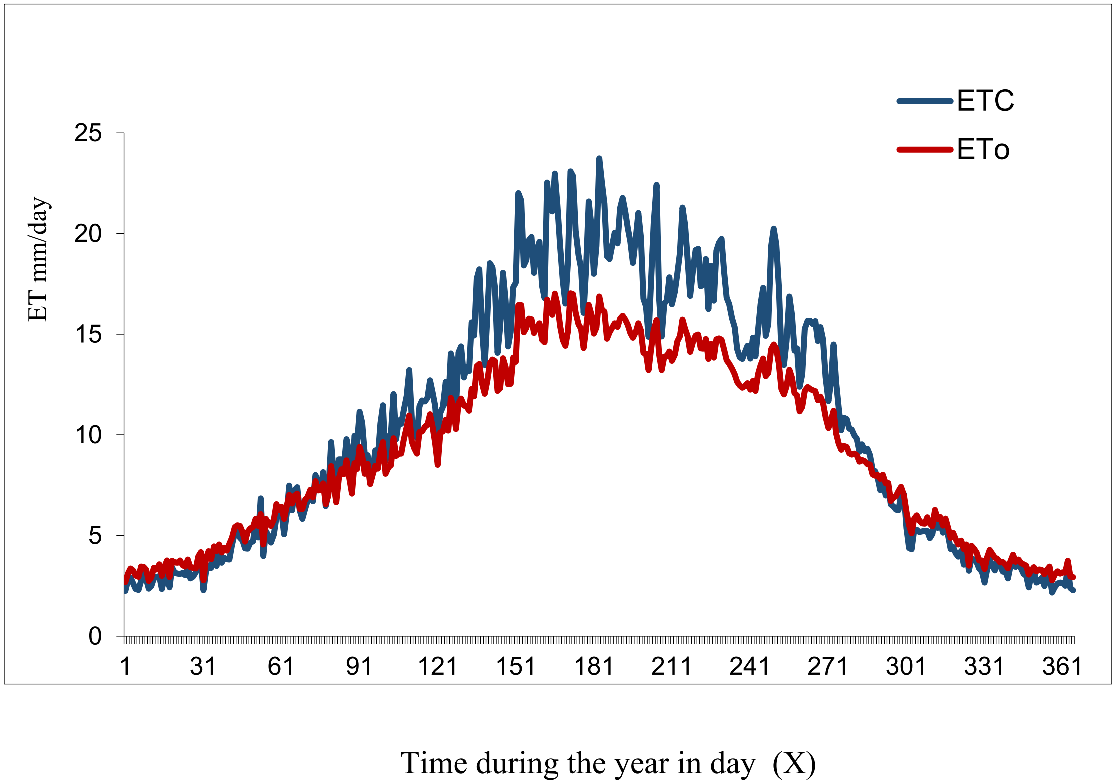

Figure 3: The daily crop evapotranspiration (ET_{Cadj}) of the palm trees for the period from 1/1/2023 to 31/12/2024

Irrigation Intervals

Irrigation intervals are one of the most important indicators for accurate irrigation scheduling. The number of days between two consecutive irrigations is determined based on the amount of readily available water in the root zone (RAW) and the average daily plant water consumption (ETc), calculated monthly. As the data in Table 3 show, the shortest irrigation intervals occurred during the summer months (June–August), when the interval was only 5 to 6 days to avoid water stress on the trees. In the colder months, such as January and December, the interval increased to more than 32 days, reflecting the significant reduction in water consumption due to lower temperatures and increased biological activity. These results are consistent with FAO reports and local and regional studies, which emphasize the importance of reducing irrigation intervals during peak summer and adopting flexible schedules that take into account climate change and the phenological stage of palm trees.

Table 3: Standard crop coefficients (Kc), adjusted crop coefficients (Kc_{adj}), reference evapotranspiration (ETo), and yield evapotranspiration (ETc) values, and monthly irrigation interval Ii for date palm cultivar Barhi.

Month	FAO Kc	Kc_{adj}	ETo	ETc	Ii (Day)	ETc mm/month
Jan	0.8	0.77	2.86	2.2	32	69
Feb	0.8	0.81	4.28	3.5	21	97
Mar	0.89	0.93	6.14	5.7	13	178
Apr	1	1.02	7.92	8.1	9	235
May	1	1.10	10.26	11.3	6	350
Jun	1	1.12	13.33	15.1	5	452
Jul	1	1.15	12.68	14.6	5	453
Aug	1	1.10	11.82	13.1	6	405
Sep	1	1.11	10.53	11.7	6	351
Oct	0.86	0.90	6.77	6.3	12	195
Nov	0.8	0.80	4.17	3.4	22	101
Dec	0.8	0.78	2.89	2.3	32	71

Water-Saving Ratio

The controlled irrigation strategy is designed to minimize water consumption while sustaining an adequate level of economic production. Figure 4 presents the annual irrigation water savings (%) for the irrigation levels applied in the experiment during the 2023 and 2024 seasons, relative to the full irrigation (TC) treatment. The irrigation water savings rates applied in the experiment across all growth stages were 55.2% for treatment T1, 35.1% for treatment T2, and 15.1% for treatment T3. The findings are consistent with those of Cui et al. (2007), who demonstrated in their experiment that all irrigation deficit factors resulted in a 5–18% decrease in water consumption and a 13–25% savings in irrigation water relative to the full irrigation treatment. The findings of Sabri et al. (2017) are corroborated, indicating that water savings of 19–39% can be attained through the application of low irrigation levels for date palms.

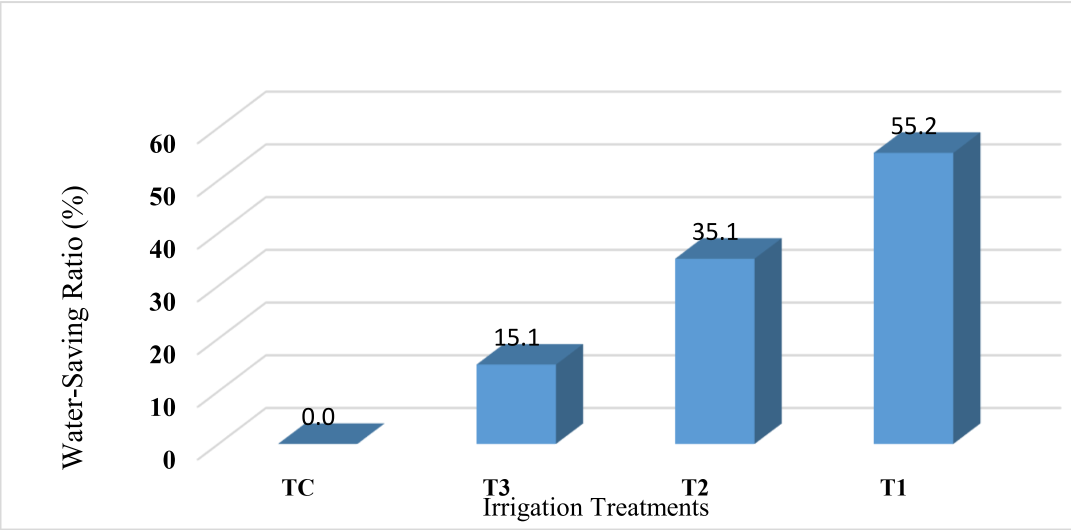

Figure 4: The effect of Irrigation treatment level on Water-Saving Ratio

The yield of date palm

The analysis of variance (ANOVA) results presented in Table 4 indicate a significant effect of both irrigation level (IRRLEVEL) and year on the total yield of the Barhi date palm cultivar ($P < 0.05$). However, the interaction between irrigation level and year (IRRLEVEL × year) did not yield a significant effect ($P = 0.705$), suggesting that the response of the palm trees to irrigation levels remained consistent across the two study seasons without statistically significant interference. The LSD test results for pairwise comparisons among irrigation levels indicated significant differences between treatments. Specifically, treatments T3 (188 m^3/tree/season) and TC (221 m^3/tree/season) significantly outperformed T1 (99 m^3/tree) and T2 (143 m^3/tree), with no significant differences observed between T3 and TC. The data suggests that raising irrigation from 188 to 221 m^3/tree did not result in a significant yield increase, indicating that the plant's water saturation threshold was attained at T3, and the additional irrigation at T4 did not enhance yield. The results align with the findings of Al-Ghobari et al. (2013) and Al-Hammadi and Al-Shihi (2016), which indicate that exceeding the optimal irrigation water level does not guarantee yield improvement and may lead to water waste without economic advantage. No significant differences were observed between treatments T1 and T2, suggesting that the increase in irrigation from 99 to 143 m^3/tree did not yield a substantial effect on productivity, indicating that the water requirements of the plants were not met in these treatments. This observation corroborates the findings of Khierallah et al. (2015), which indicated that date palm trees necessitate adequate water supply during essential growth phases to facilitate optimal fruit growth and development. The data indicated a significant increase in average yield for the 2024 season (97.61 kg/tree) compared to the 2023 season (89.67 kg/tree), reflecting a difference of approximately 7.94 kg/tree. The difference was statistically significant at the 0.05 probability level. The observed improvement can be ascribed to climatic conditions in the second season, the maturity and productivity of the trees, or the beneficial effects of agricultural treatments implemented during the experimental period, as noted by Al-Muaini et al. (2020) in their research on seasonal variations in palm productivity. The findings suggest that the T3 irrigation level (188 m^3/tree/season) is optimal from agricultural and economic viewpoints, as it yields the highest significant output while utilizing the least amount of water relative to the TC treatment, thereby improving water-use efficiency. The coefficient of determination for the model ($R^2 = 0.696$, Adjusted $R^2 = 0.663$) suggests that the statistical model accounts for approximately 70% of the total variance in yield, demonstrating the model's effectiveness in elucidating the data.

Table 4: Total yield per tree at harvest of 'Barhi' dates as affected by irrigation rate, seasons 2023 and 2024

Treatments Water regime (IRRLEVEL)	Yield (kg per tree)	W.P(kg/m3)
T1 (99 m³/tree/season)	76^{b}	0.77^{a}
T2 (143 m³/tree/season)	77^{b}	0.54^{b}
T3 (188 m³/tree/season)	110^{a}	$0.59^{b,c}$
TC (221 m³/tree/season)	111^{a}	0.50^{c}
F-test	*	*
LSD (0.05)	8.17	0.0713
Year		
2023	89.674^{b}	0.57^{b}
2024	97.6^{a}	0.63^{a}
F-test	*	*
LSD (0.05)	5.79	0.0781

Crop Water Productivity - CWP

Crop water productivity (CWP) In contrast to yield, treatment T1 had the highest W.P (0.77 kg/m³), which was considerably higher than the other treatments (^{a}), as illustrated in Table 4. Despite this, it registered the lowest yield. The water productivity was considerably reduced in treatments TC, T3, and T2, as evidenced by the significantly lower W.P. Doorenbos & Kassam (1979) reported that water productivity is typically higher at low to moderate irrigation levels, which is consistent with this result. The minimal quantity of irrigation water used in T1 is correlated with high water productivity, which in turn increase water productivity. Al-Qurashi (2016) also reported that CWP increases when irrigation water is reduced, provided that the yield is not substantially impacted. This is consistent with the aforementioned. Mattar et al., (2021) also claimed that excessive vegetative growth results from over-irrigation, but there is no corresponding increase in yield. Conversely, treatment T1's superior water productivity renders it optimal in water-scarce environments, despite the fact that it did not attain the highest yield. In this context, Al-Ghobari et al. (2013) achieved comparable outcomes with date palms. They observed that water productivity was enhanced with minimal yield loss when irrigation was reduced to 60–70% of the total requirement. The findings are also in accordance with Ismail et al. (2014), who reported that the optimal irrigation water use (0.8 m^3/kg/tree) was achieved by utilizing 65% of the total water requirement of date palms, which in turn maximized date productivity.

Conclusion and Recommendations

Conclusion

The study revealed that the reference evapotranspiration (ETo) in the Abu Al-Khaseeb area, southern Iraq, exhibits clear seasonal variation. Adjusting the crop coefficient (Kc adj) based on local climatic factors (wind, relative humidity, plant height) improved the estimation of crop evapotranspiration (ETc). The monthly irrigation intervals (Ii) ranged from 5 to 32 days depending on the month, highlighting the importance of adjusting the irrigation schedule to phenological and climatic changes. The results demonstrated the effectiveness of full irrigation in improving production. They also highlighted the importance of using low irrigation rates in improving water productivity under resource scarcity, without significantly impacting yield. The lack of a significant interaction between year and irrigation coefficient indicates the stability of Barhi palm response to irrigation treatments across the two study seasons, enhancing the generalizability of the results under similar climatic conditions.

Recommendations

Adopting an adjusted crop coefficient (Kc adj) based on local climatic characteristics rather than generalized standard values are recommended to improve the accuracy of water requirement estimation and reduce losses. Treatment T3 is recommended in areas with moderate water availability, as it achieves a balance between water quantity and yield. Treatment T1 is ideal in environments with limited water resources, achieving maximum water use efficiency.

Acknowledgments

The authors express gratitude to the College of Agriculture, University of Basrah, for providing field facilities, equipment, and technical support throughout the research. Appreciation is also sent to the Date Palm Research Centre for their assistance in data gathering and laboratory analysis.

References

Abdul Salam, M., & Al Mazrooei, S. (2006, February). Crop water and irrigation water requirements of date palm (Phoenix dactylifera) in the loamy sands of Kuwait. In *III International Date Palm Conference 736* (pp. 309-315).

Ahmed Mohammed, M. E., Refdan Alhajhoj, M., Ali-Dinar, H. M., & Munir, M. (2020). Impact of a novel water-saving subsurface irrigation system on water productivity, photosynthetic characteristics, yield, and fruit quality of date palm under arid conditions. *Agronomy*, *10*(9), 1265.

AI-Baker, A. (1972). *The Date Palm*. Ministry of Higher Education: Baghdad, Iraq.

Al Hinai, A., & Jayasuriya, H. (2021). Enhancing economic productivity of irrigation water by product value addition: Case of dates. *Journal of the Saudi Society of Agricultural Sciences*, *20*(8), 553-558.

Al-Amoud, A. I., Bacha, M. A., & Al-Darby, A. M. (2000). Seasonal water use of date palm in the central region of Saudi Arabia. *Agricultural Engineering Journal*, *9*, 51–62.

Alamoud, A. I., Mohammad, F. S., Al-Hamed, S. A., & Alabdulkader, A. M. (2012). Reference evapotranspiration and date palm water use in the kingdom of Saudi Arabia.

Al-Ghobari, H. M., & Mohammad, F. S. (2013). Water use efficiency and yield of date palm under different irrigation methods in Saudi Arabia. *Irrigation Science*, *31*(5), 1119–1129.

Al-Hammadi, M. S., & Al-Shihi, M. (2016). Impact of irrigation regimes on growth and yield of date palm cultivars. *Emirates Journal of Food and Agriculture*, *28*(1), 35–42.

Alihouri, M. (2021). Lysimertic determination of crop coefficient and evapotranspiration of date palm in the fourth and fifth years of growth. *Irrigation Sciences and Engineering*, *44*(1), 33-45.

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). *Crop evapotranspiration: Guidelines for computing crop water requirements* (FAO Irrigation and Drainage Paper

Al-Muaini, A., Green, S., Dakheel, A., Abdullah, A. H., Abou Dahr, W. A., Dixon, S., ... & Clothier, B. (2019). Irrigation management with saline groundwater of a date palm cultivar in the hyper-arid United Arab Emirates. *Agricultural Water Management*, *211*, 123–131.

Al-Muaini, M. S., Al-Yahyai, R. A., & Al-Kindy, M. (2020). Climatic factors and seasonal influence on yield of date palm in arid environments. *Agricultural Water Management*, *240*, 106291.

Al-Mulla, Y., & Al-Gheilani, H. M. (2017). Increasing water productivity enhances water saving for date palm cultivation in Oman. *Journal of Agricultural and Marine Sciences*, *22*(1), 87–91.

Al-Omran, A., Eid, S., & Alshammari, F. (2019). Crop water requirements of date palm based on actual applied water and Penman–Monteith calculations in Saudi Arabia. *Applied Water Science*, *9*(4), 69.

Al-Omran, A., Louki, I., & Alshammari, F. (2022, March). Deficit irrigation: a viable option to improve irrigation efficiency of date palm in Saudi Arabia. In *VII International Date Palm Conference 1371* (pp. 319-326).

Al-Qurashi, A. D., Ismail, S. M., & Awad, M. A. (2016). Effect of Water Regimes and Palm Coefficient on Growth Parameters, Date Yield and Irrigation Water Use of Tissue Culture-Regenerated ‘Barhee’ Date Palms Grown in a Newly Established Orchard. Irrigation and Drainage, 65(4), 491-501.

Ayers, R. S., & Westcot, D. W. (1985). *Water quality for agriculture* (Vol. 29, p. 174). Rome: Food and agriculture organization of the United Nations.

Cai, J., Liu, Y., Lei, T., & Pereira, L. S. (2007). Estimating reference evapotranspiration with the FAO Penman–Monteith equation using daily weather forecast messages. Agricultural and Forest Meteorology, 145(1-2), 22-35.No. 56). FAO.

Dhaouadi, L., Besser, H., Karbout, N., Al-Omran, A. M., Wassar, F., Wahba, M. S., Yaohu, K., & Hamed, Y. (2021). Irrigation water management for sustainable cultivation of date palm. *Applied Water Science*, *11*(11), 171.

Doorenbos J, Kassam AH (1979). Yield Response to Water. FAO Irrigation and Drainage paper No. 33, FAO, Rome, Italy, p. 193.

Doorenbos, J., & Pruitt, W. O. (1977). Guidelines for predicting crop water requirements.

FAO and AOAD. (2023). *Value chain study – Date palm in the Arab region*. Cairo, FAO. https://doi.org/10.4060/cb9917en

FAO. (2008). *Proceedings, Workshop on Irrigation of Date Palm and Associated Crops*. Damascus, Syrian Arab Republic, May 27–30.

FAOSTAT. (2019). *FAO Statistics online*. http://www.fao.org/faostat/en/#data/QC

Geerts, S., & Raes, D. (2009). Deficit irrigation as an on-farm strategy to maximize crop water productivity in dry areas. *Agricultural Water Management*, *96*(9), 1275–1284.

Hameed, M., Moradkhani, H., Ahmadalipour, A., Moftakhari, H., Abbaszadeh, P., & Alipour, A. (2019). A review of the 21st century challenges in the food-energy-water security in the Middle East. *Water*, *11*(4), 682. https://doi.org/10.3390/w11040682

Ismail, S. M., Al-Qurashi, A. D., & Awad, M. A. (2014). Optimization of irrigation water use, yield, and quality of 'Nabbut-Saif' date palm under dry land conditions. *Irrigation and Drainage*, *63*(1), 29–37.

Kambou, D., Xanthoulis, D., Ouattara, K., & Degré, A. (2014). Concepts d'efficience et de productivité de l'eau (synthèse bibliographique). *Biotechnologie, Agronomie, Société et Environnement*, *18*(1).

Karamollacheab, Aref, Seyed Majid Mirlatifi, & Ali Mokhtasi Bidgoli (2025) Effects of deficit irrigation combined with the use of biochar and compost on the growth, yield and water use efficiency of green pepper. Water and Soil Management and modeling, 5(3), 20-36.

Kenawy, A. E., Al-Awadhi, T., Abdullah, M., Ostermann, F. O., & Abulibdeh, A. (2025). A multidecadal assessment of drought intensification in the Middle East and North Africa. *Earth Systems and Environment*, 1–20.

Khierallah, H. S. M., et al. (2015). Molecular characterization of date palm in Iraq: Diversity and identification of cultivars. In *Date Palm Biotechnology*. Springer.

Levin, I., Van Rooyen, P. C., & Van Rooyen, F. C. (1979). The Effect of Discharge Rate and Intermittent Water Application by Point-source Irrigation on the Soil Moisture Distribution Pattern. *Soil Science Society of America Journal*, *43*(1), 8-16.

Mattar, M. A., Soliman, S. S., & Al-Obeed, R. S. (2021). Effects of various quantities of three irrigation water types on yield and fruit quality of 'succary'date palm. *Agronomy*, *11*(4), 796.

Mazahrih, N. T., Al-Zu'bi, Y., Ghnaim, H., Lababdeh, L., Ghananeem, M., & Ahmadeh, H. A. (2012). Determination actual evapotranspiration and crop coefficients of date palm trees in the Jordan Valley. *American-Eurasian Journal of Agricultural and Environmental Sciences*, *12*(4), 434–443.

Mazen, S. B., El-Gindy, A. M., Arafa, Y. E., & AA, I. A. (2018). A comparative study of traditional and modern irrigation systems management for irrigating date palm trees in newly reclaimed lands. *Arab Universities Journal of Agricultural Sciences*, *26*(Special Issue 2C), 1957–1965.

Montazar, A., Krueger, R., Corwin, D., Pourreza, A., Little, C., Rios, S., & Snyder, R. L. (2020). Determination of actual evapotranspiration and crop coefficients of California date palms using the residual of energy balance approach. *Water*, *12*(8), 2253.

Pereira, L. S., Oweis, T., & Zairi, A. (2002). Irrigation management under water scarcity. *Agricultural Water Management*, *57*(3), 175–206.

Sabri, A., Bouaziz, A., Hammani, A., Kuper, M., Douaik, A., & Badraoui, M. (2017). Effect of regulated Deficit irrigation on growth and development of leaf date palm (Phoenix dactylifera L.). Cahiers Agricultures, 26(5).

Sultan, M., Hashim, B., Hassan, A., & Nasser, M. (2023). Determination of impacts of climate change on temperature and rainfall variations in some southern Iraqi governorate using GIS. *Iraqi Bulletin of Geology and Mining*, *19*(2), 151–166.

Tripler, E., Shani, U., Mualem, Y., & Ben-Gal, A. (2011). Long-term growth, water consumption and yield of date palm as a function of salinity. *Agricultural Water Management*, *99*(1), 128–134.

Yaaqoob, A. (1996). Date palm irrigation; abstracted review article by: Achtrich, W. (translated from German). *Bassel Al-Assad Journal of Agricultural Engineering Sciences*, *1*(1), 85–88.

Zaid, A. (2024). *Date palm publication* (2nd ed.). FAO Plant Production and Protection Paper Series No.156. FAO.