



Irrigation Management and Water Requirements of Date Palm in Three Oases of Tunisia

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Abstract

In Tunisia, managing the water requirements of date palm is a critical challenge due to scarce water resources and the necessity for efficient irrigation practices in oasis environments. This study aims to estimate the irrigation water requirements of date palm (cv. Deglet Nour) in three oases: Jemna, Rjim Maatoug, and Tozeur using the CROPWAT 8.0 model. Climatic data revealed similar maximum and minimum temperatures and solar radiation across the sites. However, minimum relative humidity varied significantly, recorded at 34%, 14.5%, and 8.4% in Jemna, Rjim Maatoug, and Tozeur, respectively. The annual irrigation water requirements of date palm were highest in Rjim Maatoug (1267.1 mm), followed by Jemna (1245.4 mm) and Tozeur (1044.6 mm). Water productivity values were estimated at 0.47, 0.44, and 0.59 kg·m⁻³ for Jemna, Rjim Maatoug, and Tozeur, respectively. These findings contribute to a better understanding of date palm water needs in southern Tunisia and support the development of improved irrigation scheduling and water use efficiency strategies. The use of the CROPWAT 8.0 model offers a practical tool for farmers to determine optimal irrigation quantities and frequencies for sustainable date palm cultivation.

1. INTRODUCTION

The oases of Tunisia are distributed across the governorates of Gabès, Gafsa, Tozeur, and Kébili, covering a total area of approximately 55,903 hectares (Dhaouadi et al., 2022). In addition to their social, environmental, and cultural importance, these oases hold significant economic potential, primarily based on date palm cultivation. However, they are currently experiencing various forms of degradation due to both natural and anthropogenic factors. Climate change has intensified extreme weather events, including rising temperatures that frequently exceed 45 °C during summer. Annual precipitation in these regions remains below 100 mm (INM, 1998), contributing to persistent drought conditions.

Anthropogenic pressures further exacerbate the degradation of oasis ecosystems. These include declining soil fertility due to the absence or insufficiency of organic inputs, increased planting density of date palms, and poor or unregulated use of chemical fertilizers. Additionally, inefficient irrigation water management—linked to the complex dynamics among oasis stakeholders such as Agricultural Development Groups—has led to water shortages and inequitable distribution. (Dhaouadi et al., 2017).

Water management in Tunisian oases presents significant challenges at multiple levels, from the water source to the end user. Weak governance and inadequate institutional frameworks hinder effective regulation and enforcement. For

instance, existing regulations aimed at controlling water resource use and curbing illegal well drilling have largely failed in practice. The proliferation of unauthorized wells continues due to insufficient enforcement. Authorities often appear to tolerate these illegal activities, including the uncontrolled expansion of date palm plantations, due to strong social pressures, a lack of alternative livelihoods, widespread poverty, and high unemployment. These conditions risk triggering social unrest or conflict within oasis communities.

Dhaouadi et al. (2017) identified water scarcity as a major risk to the sustainability of oasis agriculture in Tunisia. Although water management in Tunisian oases has received attention from the public sector since the 1980s—through initiatives such as the Southern Waters Master Plan and various irrigation improvement projects—farmers continue to suffer from insufficient irrigation water supply (Ghazouani et al., 2007; Dhaouadi et al., 2017).

Numerous scientific studies have addressed irrigation management in oases and under date palm cultivation, focusing on aspects such as irrigation systems, water quality, irrigation control, and water requirements (Haj-Amor et al., 2020; Dhaouadi et al., 2015; Sabri et al., 2017). In recent years, several researchers have estimated date palm irrigation water requirements using the Penman-Monteith method and field water balance approaches (Mihoub et al. 2016; Mokhtari et al. 2015; Haj-

Amoretal.2020; Al-Omran et al., 2019). Naem et al., (2012).

In Saudi Arabia, a study conducted across eight arid regions estimated date palm water requirements using both methods. The results showed a range of 7340–9500 mm/ha/year with the Penman-Monteith method and around 3550 m³/ha using the field water balance method (Al-Omran et al. 2019). In Algeria, Mokhtari et al. (2015) in the Touggourt region and Mihoub et al. (2016) in the Oued Righ Valley estimated irrigation water requirements using the CROPWAT 8.0 model. They reported values of approximately 2025 mm/year/ha and 2394.11 mm/year/ha, respectively.

In Tunisia, several researchers have also investigated the water requirements of date palm. Dhaouadi et al. (2017) estimated irrigation needs to be around 945.4 mm/year in the Dguech oasis. Similarly, Haj-Amor et al. (2020) reported that net irrigation requirements in the Metwia oasis (Gabès) are expected to increase from 1404–1514 mm/year during 2008–2018 to 1549–1941 mm/year in the 2019–2030 period.

Given the variation in water requirement estimates across different regions, the main objective of this study is to estimate the irrigation water requirements for date palm in the oases of Tozeur, Jemna, and Rjim Maatoug, based on climatic data collected from local weather stations.

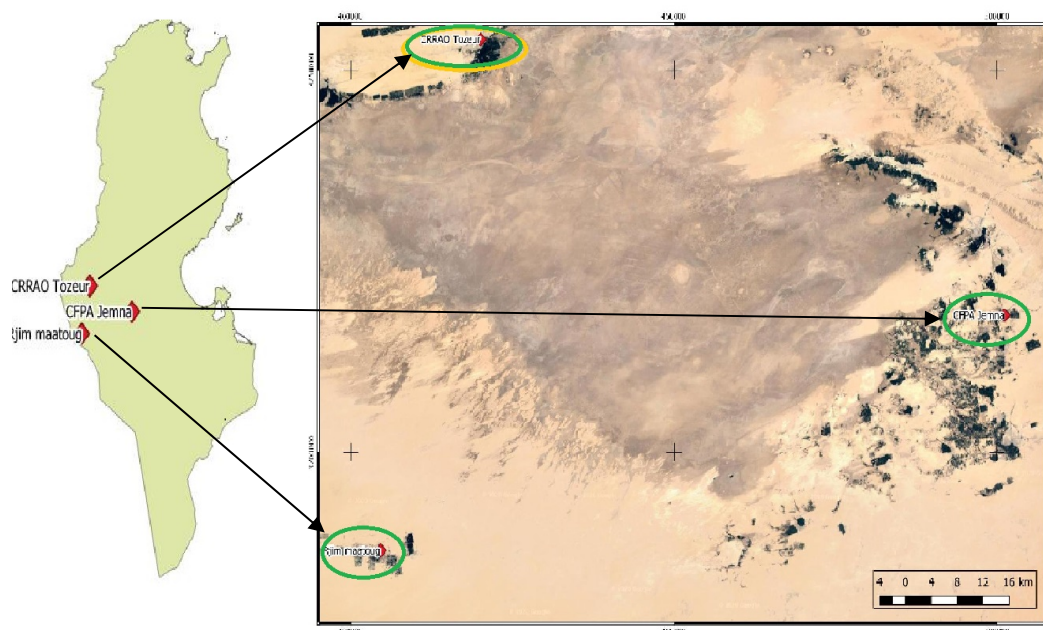


Fig. 1. Location of the experimental plots: Jemna, Rjim Maatoug and Tozeur.

2. METHODS AND RESEARCH AREA

2.1. Study site

The present study was conducted in three locations in the southwestern region of Tunisia: Tozeur, Jemna, and Rjim Maatoug (Fig. 1). A summary of the main characteristics of these sites is provided in Table 1. These oases are situated in an arid zone and are characterized by extreme climatic conditions, including very high temperatures in summer and low temperatures in winter. Average annual precipitation is approximately 186 mm. Monthly temperatures range from a maximum of 42.5 °C in August to a minimum of around 5 °C in December and January.

The soils in these oases are predominantly coarse-textured, exhibiting high permeability and low water-holding capacity. According to the World Reference Base for Soil Resources (WRB), these continental oasis soils are classified as Gypsisols. Soil pH ranges from 7.22 to 8.68, indicating moderately to strongly alkaline conditions Boulbaba et al. (2012).

The continental oases experience a hyper-arid desert climate with erratic rainfall typically not exceeding 90 mm per year. Summer temperatures can peak at 55 °C, particularly in July, and potential evapotranspiration may exceed 2000 mm per year. During spring and summer, strong sirocco winds frequently transport sand from surrounding desert areas into the oasis, contributing to environmental stress and agricultural challenges (Sghaier2010).

Groundwater and soil salinity vary across the sites, largely depending on the depth of the water table, which plays a critical role in determining irrigation suitability and long-term soil health.

2.2. CROPWAT 8.0 model

The Climate/ETo module in CROPWAT 8.0 is used to input climatic and geographical data. It requires basic site information such as country, location name, altitude, latitude, and longitude. Climatic parameters can be entered on a monthly, decadal, or daily basis and must include maximum and minimum temperatures, relative

Table 1. Description of the three study sites

Site	Tozeur	Jemna	Rjim Maatoug
Gouvernorate	Tozeur	Kebili	Kebili
Study plot area (ha)	3.7	0.6	0.8
Weather station geographic coordinates METOS (iMetos 3.3)	Altitude: 69 m Longitude: 8° 13' East Latitude: 33° 92' North	Altitude: 44 Longitude: 9.012134 Latitude: 33.605069	Altitude: 36 Longitude: 7.975387 Latitude: 33.323265
Plantation	Date palm (Deglet Nour): 30	Date palm (Deglet Nour): 93	Date palm (Deglet Nour): 125
Water source	Water tower	Water tower+ Well	Water tower+ Well
Irrigation system	Improved gravity	Micro-jet + irrigation by basin	Micro-jet + basin irrigation + improved gravity

Table 2. Inputs to Cropwat 8.0 software

Site	Tozeur	Jemna	Rjim Maatoug
Gouvernorate	Tozeur	Kebili	Kebili
Study plot area (ha)	3.7	0.6	0.8
Weather station geographic coordinates METOS (iMetos 3.3)	Altitude : 69 M Longitude : 8° 13' East Latitude : 33° 92' North	Altitude:44 Longitude:9.012134 Latitude:33.605069	Altitude:36 Longitude:7.975387 Latitude:33.323265
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Water source	Water tower	Water tower+ Well	Water tower+ Well
Irrigation system	Improved gravity	Micro-jet + irrigation by basin	Micro-jet + basin irrigation + improved gravity

humidity, wind speed, and sunshine duration (Table 2).

The Precipitation module allows the user to input rainfall data—daily, decadal, or monthly—and includes built-in calculations to estimate effective precipitation.

The Crop module is used to enter crop-specific data, including information related to the different growth stages and development phases of the crop.

Using the input data, CROPWAT 8.0 calculates actual precipitation, crop water requirements, and irrigation scheduling for date palm.

2.3. Crop water requirements

The reference evapotranspiration (ET_0) for date palm was determined using the FAO Penman-Monteith method implemented in the CROPWAT 8.0 software (Allen et al. 1998). The CROPWAT program includes procedures for calculating evapotranspiration and crop water requirements, and it allows for the simulation of water use under varying climatic, crop, and soil conditions. Accurate estimation of date palm

water requirements necessitates knowledge of several parameters related to the crop itself, as well as detailed climatic and soil data specific to the study region.

2.4. Meteorological data

Tables 3, 4, and 5 show the climatic data collected over five years (2018–2022) from meteorological stations at the study sites. The parameters include monthly temperature ($^{\circ}C$), wind speed (m/s), average relative humidity (%), sunshine hours (h), and precipitation (mm). Radiation ($MJ/m^2/day$), reference evapotranspiration (mm/day), and effective precipitation (mm) were computed by CROPWAT 8.0. Date palm crop data, such as root depth, crop coefficient, critical depletion, yield response factor, and growth stage durations, were sourced from the FAO manual 56 and integrated into the model (Allen et al. 1998). These parameters are: root depth, crop coefficient, critical depletion, yield response factor and length of crop and date palm growth stages (Clarke et al., 2001).

Table 3. Meteorological data of Jemna oasis.

Month	Temp, $^{\circ}C$		Humidity %	Wind km/day	Rain mm	Rad $MJ/m^2/day$	ETo mm/day
	Min	Max					
Jan.	-0,6	22,4	59	86	0	12,1	1,8
Feb.	-0,9	25,6	66	86	13,6	13,8	2,24
Mar.	3,5	36,3	41	147	10,4	19,8	5,08
Apr.	6,7	38,1	50	112	45,2	23,8	5,59
May	8	41,2	48	138	1	26	6,76
Jun.	17,5	46	44	104	0	28	7,24
Jul.	19,8	48,5	34	95	0	28	7,51
Aug.	20,6	41,5	50	69	0,8	24,6	5,94
Sep.	11,2	43,2	49	78	0	22,1	5,43
Oct.	4,1	34,6	57	69	29,4	15,7	3,38
Nov.	1	28,3	62	61	0,8	12,9	2,09
Dec.	1,1	23,1	65	43	0,4	12,2	1,33

Table 4. Meteorological data of Rgim Maatoug oasis.

Month	Temp, $^{\circ}C$		Humidity %	Wind km/day	Rain mm	Rad $MJ/m^2/day$	ETo mm/day
	Min	Max					
Jan.	2,5	24,8	53	26	0	12,2	1,32
Feb.	2,3	26,1	61	35	17,2	13,9	1,88
Mar.	4,7	32,9	39	61	7,4	19,9	3,47
Apr.	11,2	36,4	42	69	0	23,9	4,85
May	11,4	37,9	42	61	5,4	26	5,3
Jun.	19,5	45,6	36	43	0	28	5,96
Jul.	25,2	49,2	28	35	0,2	28	6,21
Aug.	21,3	41,5	43	43	1	24,7	5,53
Sep.	14,4	44,1	43	43	0,4	22,2	4,86
Oct.	8,2	33,6	51	43	2,8	15,8	3,01
Nov.	5,4	27,6	56	26	0,2	13	1,69
Dec.	3,5	24,7	58	17	0	12,3	1,13

Table 5. Meteorological data of Dguech oasis.

Month	Temp, °C		Humidity %	Wind km/day	Rain mm	Rad MJ/m ² /day	ET ₀ mm/day
	Min	Max					
Jan.	2,5	24,8	53	26	0	12	1,28
Feb.	2,3	26,1	61	35	17,2	13,7	1,84
Mar.	4,7	32,9	39	61	7,4	19,8	3,44
Apr.	11,2	36,4	42	69	0	23,7	4,83
May	11,4	37,9	42	61	5,4	26	5,29
Jun.	19,5	45,6	36	43	0	28	5,96
Jul.	25,2	49,2	28	35	0,2	28	6,2
Aug.	21,3	41,5	43	43	1	24,6	5,51
Sep.	14,4	44,1	43	43	0,4	22	4,83
Oct.	8,2	33,6	51	43	2,8	15,6	2,97
Nov.	5,4	27,6	56	26	0,2	12,8	1,65
Dec.	3,5	24,7	58	17	0	12,1	1,08

2.5. Reference evapotranspiration:

Reference evapotranspiration (ET₀) is the rate at which a well-watered reference crop, typically grass, loses water through evaporation and transpiration under ideal conditions (Allen et al., 1998):

$$ET_0 = \frac{0.408 \Delta (R_n - G) + \gamma \left(\frac{900}{T + 273} \right) U_2 (e_s - e_a)}{\Delta + (1 + 0.34 U_2)}$$

Where:

ET₀=reference evapotranspiration (mm/day), R_n=net radiation at the crop surface (MJ/m² perday),G=soil heat flux density (MJ/m² perday),T=mean daily air temperature at 2m height (°C), U₂= wind speed at 2 m height (m/s), e_s= saturation vapour pressure (kPa), e_a=actual vapour pressure(kPa),e_s-e_a=saturation vapour pressure deficit (kPa),Δ=slope of saturation vapour pressure curveat temperatureT(kPa/°C),and γ=psychrometric constant 169 (kPa/°C).

2.6. Crop water requirements

Crop water requirements represent the amount of water lost by cultivated date palms through evapotranspiration (ET_c). The ET_c value was calculated using the following equation:

$$ET_c = ET_0 \times K_c \quad (2)$$

K_c is the crop coefficient [-] that scales the potential grass reference evapotranspiration (ET₀) under non-water-stress conditions (Allen et al., 1998). It depends on the crop type, including factors such as crop height, canopy resistance, albedo, as well as soil and climatic parameters like soil surface evaporation, wind speed, and direction (Allen et al., 1998; Smith,

1992). This coefficient varies according to the crop species and its growth stage.

2.7. Irrigation water requirement (RI)

Irrigation water requirement is the total amount of water per unit area needed for the crop to develop normally under field conditions. It represents the additional water that must be supplied beyond effective precipitation to ensure optimal agricultural production. In other words, it is the difference between the crop’s actual evapotranspiration and the effective precipitation (P_{eff}) (Allen., 1998; Smith, 1992).

2.8. Irrigation water requirement per date palm tree:

The water requirement of the date palm in (m³/tree/day) is given by the following equation (Gafar, 2010; Ismail et al., 2014, sabri, 2017).

$$IWR = ET_0 \times K_c \times S_a \quad (3)$$

S_a is the active area of evapotranspiration of the palm tree (m²), it is calculated according to the following formula where the active radius (R_a) is equal to 90% of the radius of the surface of the vertical projection of the canopy (m) (Soltani and al ,2008).

$$S_a = \pi [(R_a)]^2 \quad (4)$$

2.9. Amount of Leaching requirement

The Leaching requirement was calculated using the following equation (Doorenbos and Pruitt 1977).

$$LR = \frac{EC_{iw}}{2 \text{Max} EC_e} \times \frac{1}{\text{Eff}} \quad (5)$$

Where LR= the fraction of the water to be applied that passes through the entire root zone depth and percolates below. EC_{iw} = electrical conductivity of irrigation water (dS / m).

EC_e = electrical conductivity of the soil saturation extract for a given crop appropriate to the tolerable degree of yield reduction (dS / m).

Max EC_e = maximum tolerable electrical conductivity of the soil saturation extract for a given crop (dS / m). Eff= leaching efficiency (90% for sandy and loamy sands).

2.10. Net Irrigation water Requirement per date palm tree

The following equation estimates the net irrigation water requirement (NIWR) of a date palm, expressed in cubic meters per tree per day ($m^3/\text{tree}/\text{day}$) (Sabri et al., 2016):

$$NIWR = \frac{IRW}{(1-LR)} \quad (6)$$

3. RESULTS

3.1. Climatic condition of the three oases

The average climatic variables for the Jemna, Rjim Maatoug, and Tozeur oases are presented in Tables 3, 4, and 5, respectively. Our results show that the highest temperatures recorded in Jemna, Rjim Maatoug, and Tozeur were 39.80°C, 41.50°C, and 41.30°C, respectively. The lowest temperatures during the study period were 10.11°C, 10.31°C, and 10.31°C, respectively.

The maximum net radiation values observed in Jemna, Rjim Maatoug, and Tozeur were 28.00, 24.40, and 25.70 MJ/m^2 , while the minimum net radiation values were 12.10, 14.50, and 8.40 MJ/m^2 , respectively.

Additionally, the highest relative humidity recorded in Jemna, Rjim Maatoug, and Tozeur was 66%, 65%, and 61%, respectively, whereas the lowest relative humidity values were 34%, 14.5%, and 8.4%, respectively.

These climatic variations suggest that while temperatures and radiation levels are generally high, promoting evapotranspiration, the relatively low minimum humidity levels, especially in Tozeur, may increase water stress for the date palms, highlighting the importance of tailored irrigation scheduling in these oases.

During the study period, the maximum wind speeds recorded were 1.70, 1.70, and 0.80 m/s

in Jemna, Rjim Maatoug, and Tozeur, respectively. The minimum wind speeds observed were 0.50, 0.20, and 0.20 m/s in the same order. Actual effective precipitation refers to the portion of total precipitation that is available for crop use after losses due to surface runoff and deep percolation. It is a key parameter in assessing local rainfall storage (LRS). The main characteristics of rainfall quantity, frequency, and intensity vary over time and space, and understanding these is crucial for optimizing its use (Clarke et al., 2001).

In this study, the Soil Conservation (S.C.) method was applied to estimate actual rainfall and determine parameters such as irrigation scheduling and water requirements for date palms (FAO, 2018). As shown in Tables 3, 4, and 5, the annual rainfall in Jemna, Rjim Maatoug, and Tozeur was 101.6 mm, 29.6 mm, and 34.6 mm, respectively, with effective precipitation values of approximately 96.5 mm, 29.1 mm, and 34.0 mm.

These results indicate that Jemna receives significantly more rainfall than the other sites, which may reduce irrigation needs there. However, the relatively low rainfall and effective precipitation in Rjim Maatoug and Tozeur highlight the necessity for careful irrigation management to sustain date palm cultivation in these arid areas.

3.2. Date palm ET_c

The results presented in Fig. 2 and Tables 3, 4, and 5 show that the crop evapotranspiration (ET_c) in Jemna, Rjim Maatoug, and Tozeur was 1398.4, 1189.73, and 1024.9 mm/year, respectively. These variations in ET_c among the study sites in southern Tunisia are closely linked to local weather conditions. The highest ET_c value was observed in Jemna, which can be attributed to its higher net radiation and temperatures.

The reference evapotranspiration (ET_0) values calculated by the CROPWAT 8.0 model for different months are also listed in Tables 3, 4, and 5. ET_0 peaked during the summer months due to elevated temperatures, reaching maximum daily values of 7.09 mm in Rjim Maatoug, 6.9 mm in Jemna, and 5.09 mm in Tozeur. Conversely, ET_0 declined during winter, with the lowest value recorded in December in Tozeur (0.9 mm/day), followed by 1.06 mm/day in Rjim Maatoug and 1.33 mm/day in Jemna, corresponding to the colder temperatures.

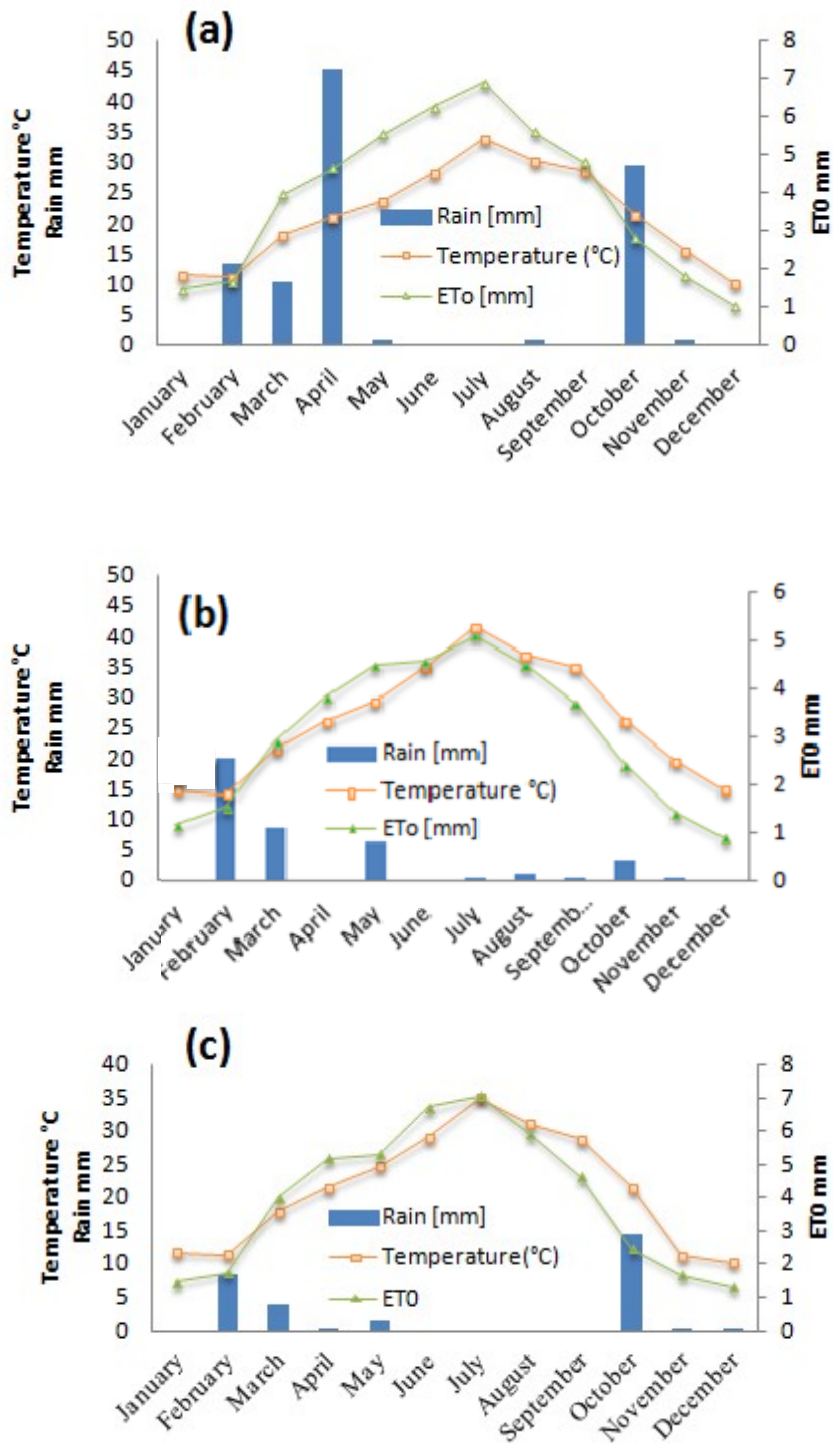


Fig. 2. Ombrothermal diagram of the plots of (a) Jemna, (b) Tozeur and (c) Rjim Maatoug, 2018-2022.

These fluctuations in ETo reflect the variability in meteorological factors across the study areas. Specifically, low relative humidity, high temperatures, and strong winds during dry seasons contribute to increased evapotranspiration rates. This indicates that water demand for date palms is significantly influenced by microclimatic differences, highlighting the need for site-specific irrigation

strategies to optimize water use efficiency and ensure sustainable agricultural production in these oases.

3.3. Net irrigation requirements (NIR)

The irrigation management is usually associated with the water requirements and irrigation schedules data of crops. The gross average of total irrigation and the net average of total

irrigation are 1576 mm and 1103.2 mm in Jemna, 1703.4 mm and 1192.4 mm in Rjim Maatoug and 1341.3 mm and 938.9 mm in Tozeur. The INR is the amount of water required for crop growth or the amount of water required to reach soil capacity on the ground. The INR is related to the climate and the culture model. Data on irrigation efficiency are needed to convert the INR into gross irrigation needs. Generally, the losses including run off, infiltration, evaporation and percolation, take place during the application and transport of irrigation water (Muñozet Grieser, 2006). The operations, such as leaching, transplantation and land preparation, needs certain water amounts. Therefore, LRS include TE losses during the application of necessary water as in the equation:

$$NIR = Etc - E_{ff} \cdot rain$$

According to the CROPWAT 8.0 model, applied on the three regions Jemna, Rjim Maatoug and Tozeur, the irrigation water requirements (IR) for the date palm in the three study areas are in the following order according to the unit (mm/year): Rjim Maatoug (1237.6) > Jemna (1148.5) > Tozeur (1010.2)

According to the Table 3, for the Jemna site, we note that there are four months of strong rainfall deficit in May, June, July and August, these deficits are respectively: 153.7, 162.5, 181.8 and 149.6 mm. The month of July is the most deficient. The month with the least deficit in irrigation water is December with a demand of 28.9 mm /month.

For the Rjim Maatoug site (Table 4), we note that there are three months of strong rainfall deficit in June, July and August, these deficits are respectively: 173.5, 185.7, 156.7 mm. The month of July is the most deficient. The month with the least deficit in irrigation water is December with a demand of 35.6 mm month⁻¹.

For the Tozeur site (Table 5), we note that there are three months of strong rainfall deficit in June, July and August, these deficits are respectively: 132.9, 151.6, 133.2 mm. The month of July is the most deficient. The month with the lowest irrigation water deficit is February, with demand of 21.9 mm month⁻¹.

3.4. Irrigation water requirement according to phenological stages

The water requirements of date palm in the three regions vary according to the phenological stages. According to Table 3, 4 and 5, the two stages which consume the most water are the fruits et stage and the B'ser or Khalal (full-size, crunchy stage, mature firm full colored stage). Indeed, the high need for irrigation water during this period is due to several factors. These two stages are the stages of fruit enlargement which take place in summer, the fruit set stage being between mid May to mid July and the irrigation water requirement during this stage for the sites Tozeur, Jemna and Rjim Maatoug are 270, 211.1 and 269.2 mm, respectively (Fig. 3). The B'ser stage is between mid July and 31 August, the irrigation water requirements during this stage for the Tozeur, Jemna and Rjim sites are 211, 330 and 344 mm, respectively (Fig. 3).

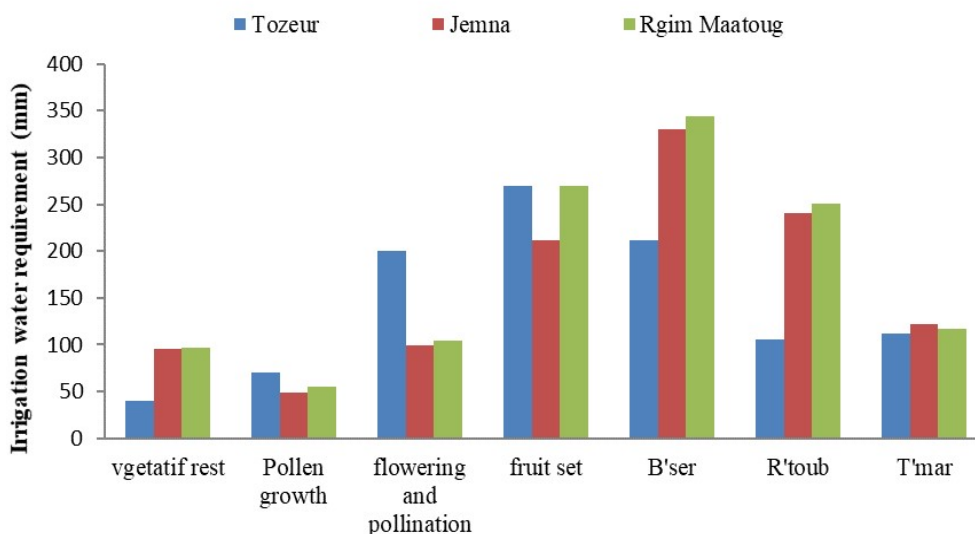


Fig. 3. Irrigation water requirements depending of phenological stages at the Tozeur, Jemna and Rjim Maatoug sites

3.5. Water requirements per date palm tree

Equation (3) and (4) (5), (6) represent the palm water requirements in (l / tree / day) in each study site. The total volumes of water input corresponding to the date palm water requirements per tree for Jemna, Rjim Maatoug and Tozeur are 49, 57 and 42 m³ / tree / year. The applied irrigation water is characterized by an electrical conductivity around of 3.1mS/cm; 3.7mS/cm and 1.8mS/cm for Jemna, Rjim and Tozeur zones, which requires an additional fraction of water to leach out salts. The annual net irrigation water requirements per tree (NIR) are in the order of 72.61 and 52 m³ / tree / year for Jemna, Rjim Maatoug and Tozeur (Fig. 4 and Table 6).

these needs are about of 945.4 mm/year in Dguech oases. This difference may be due to the climatic data recorded at the Insitustations installed at the level of the study plots which make it possible to find more precise results also soil structure.

The currently quantities distributed in the region of ElJerid for predominantly Deglet Nour plantations is a continuous notional flow of 0.75 l s ha⁻¹, i.e.2400 mm ha year⁻¹ (Dhaouadi et al. 2017), it is almost double the palm irrigation requirements calculated by Cropwat.

In Tunisian southern oases date palm groves are irrigated through the surface irrigation system. Furrow and basin techniques are considered as modified forms of flood technique in which water is directed to flow through narrow

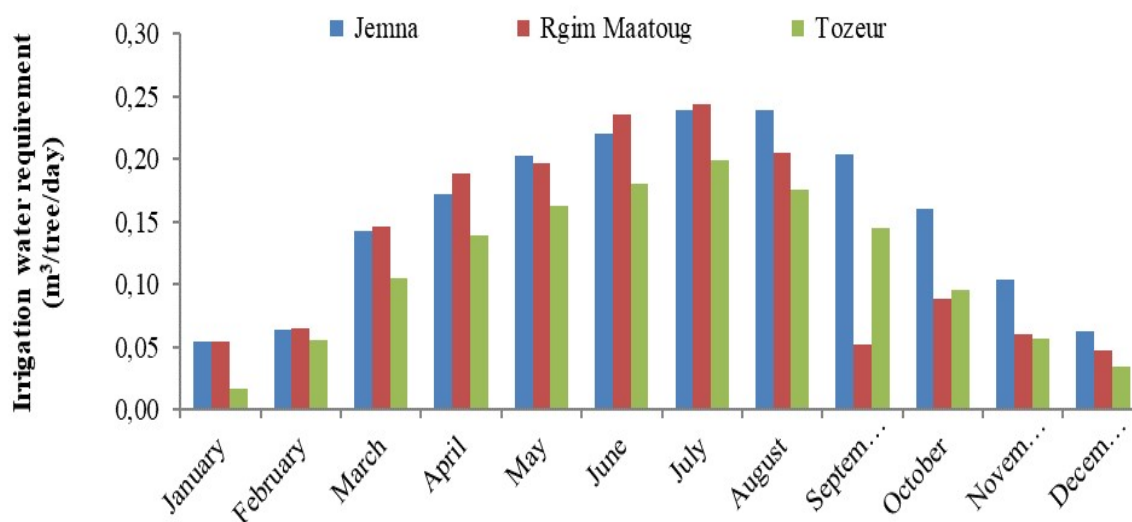


Fig. 4. Irrigation water requirements per tree of date palm at Jemna, Rjim Maatoug and Tozeur

Table 6. Net Irrigation water Requirement of date palm in Jemna, Rjim Maatoug and Tozeur

	EC (ms/cm)	IWR (m3/tree/an)	NIR (m3/tree/an)
Jemna	3,1	49	72
Rjim	3,7	57	61
Tozeur	1,8	42	52

4. DISCUSSION

The date palm irrigation water requirements for the Jemna, Rjim Maatoug and Tozeur study sites are 1148.5-, 1237.6- and 1010.2-mm year ha⁻¹, respectively, almost the same results were found by Dhaouadi and al. (2017), who revealed that

channels established between palm trees rows.

While this method is less expensive and easy managed in flatted lands never the less, the technique suitability in sandy soils is rather low due to high loss of water through leaching and evaporation. The depletion of water resources is

clearly a big problem in the southern oases of Tunisia, the illegal extension of oases as a result of private initiative and access to water through digging wells has led to over-extraction of renewable ground water, and accelerating the phenomenon of saline intrusion from the saline areas (e.g. Chott Djerid in Kebili) (Omrani, N., & Ouessar 2009).

In addition, most of the farmers managed the water by their own way in the absence of a specific recommended method, which leads to considerable water loss (Mechergui and Van Vuren, 1998). Salinity also is one of the major problems in the irrigated oases in Tunisia. The gypsi ferrous soil covering the oases land is encrusted alluvial deposits that are salty in the deep horizons. 47 percent of the ground water has salinity higher than 3 g/l, in Tozeur oasis for example, the salinity of the shallow groundwater aquifer reached an average of 7.23 g/l (Marlet et al., 2009a and Bouarfa et al., 2009). The over-pumped ground water coupled with poor drainage system lead to soil degradation by saline water due to the seeping of saline water from different sources such as Chotts, (e.g. Chott Djerid) or rises of the saline underground water. The low elevation between oases and Chotts cause difficulties for ground water discharge and thus increase salt accumulation in oasis soils (Belloumi and Matoussi 2006). In addition, stagnant water used for irrigation is a constant source of salts, which increase the salt concentrations in the soil causing more difficult conditions for absorption of moisture and nutrients by the plant and eventually die from dehydration (Marlet, al. 2009b).

This excess water can worsen the quality of oasis soils by increasing salinization which causes the accumulation of salts difficult to evacuate by leaching.

The salinity is usually associated with the irrigation water quality. It could interact with other constraints by aggravating the effect of water stress during the summer period and by applying abundant irrigations aggravating the water logging during the winter period. The engorgement is mainly due to the dysfunction of the drainage system which causes the suffocation of the root system which induces the delay in flowering and harvesting and reduces yields especially for the sensitive variety Deglet Nour (Ghazouani et al., 2007).

Water Productivity

Date palm cultivation plays a vital economic role in southern Tunisia. However, effective irrigation water management has become increasingly critical due to reduced water availability driven by high evaporation rates and diminishing groundwater recharge. These challenges significantly threaten the sustainability of oasis agroecosystems. Table 7 supports this by showing productivity levels per hectare in the Jemna, Rjim Maatoug, and Tozeur oases as 5447.37 kg/ha, 5447.37 kg/ha, and 5979.99 kg/ha, respectively.

Irrigation water productivity of date palms in the Jemna, Rjim Maatoug, and Tozeur experimental sites was 0.47, 0.44, and 0.59 kg/m³, respectively, while farmers in these regions achieved lower values of 0.23, 0.23, and 0.25 kg/m³, respectively. The total water applied by farmers—approximately 24,000 m³/ha/year—reflects poor water management practices, which may also include other activities that threaten the sustainability of the oasis ecosystems.

In the same context, Mekki et al. (2013) highlighted that the oasis agroecosystem sector in Tunisia suffers from weak governance and institutional arrangements. Furthermore, anthropogenic factors and climate change will exacerbate problems in southern Tunisia, which is projected to experience warming of 1.1°C by 2030 and 2.1°C by 2050 (Verner, 2013). Date production is expected to be severely affected by these changes, as some areas currently suitable for cultivation may no longer support economically viable date palm farming (Shabani et al. 2012).

Therefore, institutional regulations must be strengthened to better control irrigation water use and prevent illicit groundwater drilling. Current enforcement of laws to curb illegal well drilling has been insufficient, leading to increased unauthorized extraction in the oases. It is also crucial to enhance farmers' knowledge and promote the adoption of sustainable water management practices to ensure the long-term viability of these fragile ecosystems.

5. CONCLUSION

The use of the CROPWAT 8.0 model provided valuable results. The irrigation requirements and schedules for date palms determined in this study are specific to the local conditions and can be explained by the climatic and soil parameters

unique to each region. The annual water requirements for date palms in Tozeur, Jemna, and Rjim Maatoug were estimated at 1044.6, 1245.4, and 1267.1 mm/year/ha, respectively. Corresponding irrigation water requirements were 1148.5, 1237.6, and 1010.2 mm/year/ha.

Policy measures should focus on capacity building for farmers and strengthening institutional support. Farmers need to acquire technical knowledge to better manage their lands, which can be achieved by improving extension services through various strategies and programs that encourage knowledge exchange among farmers.

To successfully implement sustainable management practices, farmers must demonstrate eagerness and commitment by abandoning mismanagement practices, taking responsibility for their actions, and moving away from a passive attitude that blames external factors.

Finally, the study's findings can guide policy changes aimed at protecting farmers most affected by land degradation and encouraging them to diversify their income sources by adopting alternative livelihoods, thereby improving household resilience.

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