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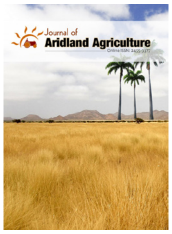

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Determination of irrigation requirement for tomato using FAO-CROPWAT model in the Arid Region

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ABSTRACT

Food security presents a significant challenge in arid regions, exacerbated by water scarcity due to climate change. Tomato is one of the top agricultural crops around the world, in which it is needed to investigate its irrigation water requirements for each region, especially in the arid regions. This work mainly aims to estimate the irrigation water requirements and irrigation schedules for cultivating tomato in Ras Al Khaimah (RAK), United Arab Emirates (UAE). This would be done by utilizing the FAO-CROPWAT 8.0 Model and CLIMWAT 2.0. The findings of this research support efficient water use by utilizing the advanced modeling tools. The outcomes will inform and enhance irrigation water management practices for farmers, farm owners, and policymakers, contributing significantly to sustainable development goals and the resilience of agricultural systems in water-limited environments.

KEYWORDS: FAO-CROPWAT, Irrigation water requirements, Irrigation schedules, Sandy soil, Tomato

INTRODUCTION

The UAE is located in the arid region of the world with challenging soil properties due to its sandy nature associated with low water holding capacity and poor nutrient content resulted in low fertility (Shahin *et al.*, 2018a; Shahin & Al Yafei, 2023). Ras Al Khaimah (RAK) is one of the seven UAE's Emirates located in the northern region. According to the UAE soil survey, among the seven Emirates, RAK has the best quality soil for agricultural purposes. Accordingly, can contribute effectively to the country's crops' production and food security (Ajaj *et al.*, 2018).

The global population explosion leads to highlight food security as a serious topic, especially in the desert regions (Shahin & Salem, 2014), where climate change consequences (e.g., temperature raise, limited precipitation) can be severe. Therefore, it is always needed to conserve fresh water resources and to apply it effectively by the proper management (Shahin & Salem, 2015), in which estimating the irrigation watering amounts can be a key factor in sustainable urbanization by reducing unnecessary water lost due to irrigation activities (Shahin *et al.*, 2018b; Ajaj *et al.*, 2019) resulting in contributing to United Nation (UN) sustainability development goals (Mainly SDG 2, and partially SDGs 11, 13, 15).

Tomato (*Solanum lycopersicum* L., Family: Solanaceae) (Ewaid *et al.*, 2019), is the second-largest crop cultivated and consumed worldwide. Tomatoes are widely popular not only for their taste, pleasant flavor, and multi applications in recipes and food industry, but also for their nutritional benefits. Tomato fruits are rich in vitamins, minerals, and high levels of antioxidant substances (carotenes, especially lycopene), which have been associated with a reduced incidence of cardiovascular diseases and certain types of cancer (Dariva *et al.*, 2020).

In fact, this popular agricultural crop is a high-water demand crop, and thus faces significant challenges when grown in arid regions due to water scarcity and the situation became much challenging with climate change (Dariva *et al.*, 2020). Several studies have explored various strategies to sustainably optimize water management for tomato cultivation in such challenging environments (Khapte *et al.*, 2022; Burato *et al.*, 2024).

The Food and Agriculture Organization (FAO) has developed advanced modeling tools to simulate the response of various field crops to both quantitative and qualitative irrigation management (Solangi *et al.*, 2022; Mehasen & Mansour, 2024). Consequently, the main aim of this study is to quantify the irrigation water requirements and irrigation schedule for tomato, considering RAK as the study location and modeling by the Food and Agriculture Organization FAO-CROPWAT based on climatic data.

MATERIALS AND METHODS

Study Area

RAK had been selected as the study area as shown below (Figure 1). It is located in the northern region of the UAE (Latitude of 25-26 N and Longitude of 55-60 E), with an area of 2,486 km^2. RAK is bordered from the South and the Northeast by Oman and shares borders with the emirates of Umm Al Quwain, Sharjah, and Fujairah.

Model Description and Required Data

CROPWAT 8.0 is a decision-support computer program developed by the FAO to calculate irrigation requirements (IRs) based on climate, soil and crop data. Besides, the program allows the development of irrigation schedules for different management conditions. The program includes general data for various crop features, local climate, and soil properties and helps enhance irrigation schedules and the computation of scheme water supply for different crop patterns under irrigated and rainfed conditions. Four types of data are required for using the CROPWAT software, climate, rainfall, crop and soil data (Muñoz & Grieser, 2006; Takács *et al.*, 2021; Solangi *et al.*, 2022).

Climatic data for around thirty years (1971–2000) were gathered from the station of Ras Al Khaimah International Airport (longitudes: 55.93°, latitudes: 25.61°, altitude: 31 m), obtained from the FAO-CLIMWAT 2.0 which is a climatic database to be used in association with the CROPWAT program and which allows the calculation of IRs and irrigation schedules of tomato grown in RAK (FAO, 2018).

CLIMWAT contains long-term monthly climatic parameters with the coordinates and altitude of the location. These parameters are monthly maximum and minimum temperature (°C), mean relative humidity (%), wind speed (km/h), sunshine hours (h), rainfall data (mm), and effective rainfall (mm). CLIMWAT utilizes climatic data to quantify the amount of evapotranspiration (ET_0) based on ET Penman-Monteith. The effective rain (mm) was calculated based on the United States Department of Agriculture (USDA) soil conservation (S.C.) method (FAO, 2018).

The crop data for tomatoes were obtained from the FAO Manual 56 details and were added to the CROPWAT program, including rooting depth, crop coefficient, critical depletion, yield response factor, and length of plant growth stages (Clarke *et al.*, 2001). Planting dates were taken according to the Dates for Planting Vegetables and Fruits in the United Arab Emirates published by the Ministry of Climate Change and Environment (DEAT, 2018).

The soil parameters obtained from the FAO CROPWAT 8.0 model include detailed information on the soil near the climatic station (e.g., total available soil moisture, maximum rain infiltration rate, maximum rooting depth and initial soil moisture depletion). The United States Department of Agriculture (USDA) soil conservation (S.C.) method was used in this study (FAO, 2018).

RESULTS AND DISCUSSIONS

The data which were entered into the CROPWAT and CLIMWAT software included the country (UAE), climatic station (Ras Al Khaimah International Airport), type of crop (tomato), date of cultivation (October), and soil type (Sandy: light). Once all the data were entered into the software, it calculated the climatic parameters, ET_0, effective rainfall, irrigation requirement and crop irrigation scheduling for tomato in the study area. These findings and other outputs are presented and discussed in this section.

Climatic Conditions and Reference Evapotranspiration (ET_0)

The climatic characteristics of RAK, including temperature, humidity, wind speed, sunshine hours, and radiation, were critical inputs for determining the reference evapotranspiration (ET_0). As shown in Table 1, the data, spanning the entire year, showed significant variations in these parameters, influencing the water requirements of tomato plants. For instance, the maximum temperatures ranged from 24.8 °C in January to 42.7 °C in July, while the minimum temperatures varied from 11.8 °C to 28.6 °C, indicating a high degree of seasonal fluctuation. Such variations necessitate careful adjustment of irrigation practices to match the changing water needs of the crop.

Figure 1: Ras Al Khaimah Emirate based on google earth

The ET_0 of the crop under consideration (ETc) can be obtained by adjusting ET_0 using crop coefficient (Kc) as in Equation (1) as follows (Djaman & Irmak, 2013):

$$ET_0 = ETc/K \tag{1}$$

The reference evapotranspiration (ET_0) values obtained from the climatic data highlight the substantial water demand for tomato cultivation in RAK. Recent studies emphasize the critical role of ET_0 in irrigation planning. Solangi *et al.* (2022) demonstrated that accurate ET_0 determination is essential for effective irrigation scheduling to meet crop water needs. The observed monthly ET_0 values (Table 1), ranging from 3.00 mm/day in January to 8.71 mm/day in June, reflect significant seasonal variations that must be considered for efficient water management. These findings are consistent with regional studies that stress the importance of adapting irrigation practices to seasonal climatic changes (Dingre & Gorantiwar, 2020).

Table 1: Climatic characteristics of Ras Al Khaimah

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ET_0
	°C	°C	%	Km/day	hours	MJ/m²/day	Mm/day
January	11.8	24.8	67	190	7.7	14.6	3.00
February	12.9	25.9	65	199	7.8	16.8	3.53
March	15.5	29.5	59	225	7.7	19.0	4.70
April	18.9	35.2	49	225	9.5	23.4	6.57
May	22.6	39.3	43	242	11.1	26.6	8.21
June	25.6	42.1	47	251	10.9	26.4	8.71
July	28.5	42.7	47	242	9.8	24.6	8.51
August	28.6	41.9	52	242	10.0	24.3	8.18
September	24.7	40.1	54	199	10.0	22.8	6.93
October	20.7	36.7	58	173	9.8	20.0	5.45
November	16.6	31.4	62	173	9.3	16.9	4.05
December	13.5	26.8	65	173	7.6	13.8	3.08
Average	20.0	34.7	56	211	9.3	20.8	5.91

Table 2: Effective rainfall data

Month	Rain	Eff. rain
	mm	mm
January	12.8	12.5
February	35.7	33.7
March	35.0	33.0
April	12.5	12.3
May	2.8	2.8
June	0.0	0.0
July	0.6	0.6
August	0.3	0.3
September	1.3	1.3
October	6.4	6.3
November	8.0	7.9
December	17.4	16.9
Average	132.8	127.6

Effective Rainfall

Effective rainfall data revealed that the annual rainfall in RAK was low, with an average effective rainfall of 127.6 mm (Table 2). The distribution of rainfall was uneven, with the majority occurring in the winter months. This limited and sporadic rainfall highlights the critical need for efficient irrigation systems to ensure consistent water supply throughout the growing season. Similar studies in arid regions, such as those by Solangi *et al.* (2022), underscore the necessity of irrigation to supplement low rainfall in maintaining crop productivity. The effective use of limited rainfall through efficient irrigation practices, as demonstrated in this study, is crucial for sustainable agriculture in arid climates.

Irrigation Requirement and Irrigation Scheduling

Tomato, being a high-water-demand crop, necessitates precise irrigation requirements and scheduling to optimize yield and quality. The crop data and soil characteristics used to determine these irrigation needs and schedules are presented in Tables 3 and 4, respectively. Additional details related to the cultivated crop are illustrated in Figure 2. The cultivation data, including the critical depletion fraction (0.4) and rooting depths (1 m), align with findings from Dariva *et al.* (2020), who underscore the importance of accurate crop-specific parameters for tailoring irrigation practices. The growth periods and corresponding water requirements identified in this study match the developmental stages reported in the literature, ensuring efficient water supply during critical growth phases.

The study presented the irrigation requirements for tomatoes in Figure 3, while the irrigation schedules, including readily available moisture (RAM) and total available moisture (TAM), are depicted in Figure 4. As shown in Figure 3, the highest irrigation requirement (34 mm/dec) occured in October at the beginning of the planting period, fluctuating between 29 and 33.5 mm/dec according to the crop growth period and climatic considerations. The peak irrigation demand was recorded in the middle of the crop development stage and at the beginning of the mid-season stage, followed by a sharp reduction in the late season by the end of February.

Table 3: Tomato cultivation data

Planting and harvesting date	Critical depletion fraction	Rooting depths (m)	Crop Growth Periods (Days)			
			Initial	Crop Development	Mid-Season	Late Season
1 October-22 February	0.4	1	30	40	45	30

Table 4: Soil characteristics data

Total available soil moisture (FC-WP)	Maximum rain infiltration rate	Maximum rooting depth	Initial soil moisture depletion (as % TAM)
60.0 mm/m	40 mm/day	0.90 m	0%

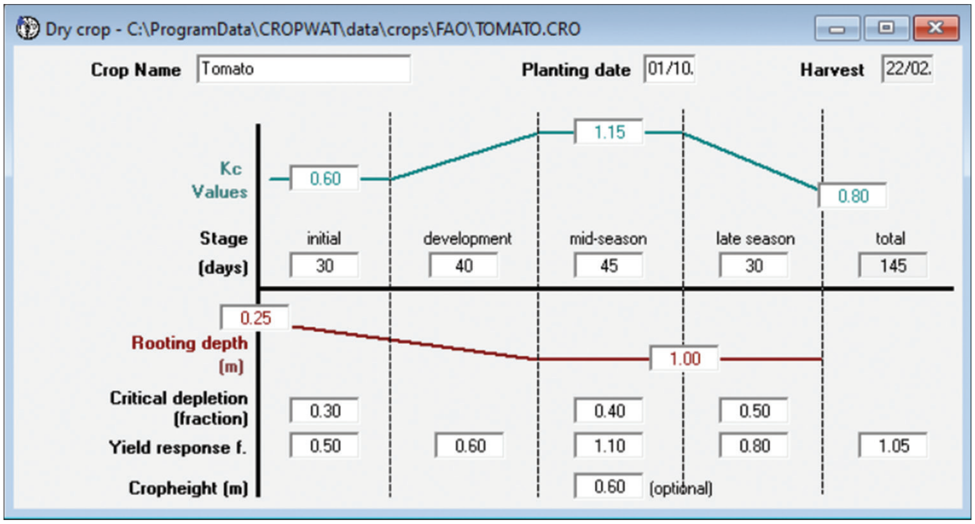

Figure 2: Crop data during the cultivation period

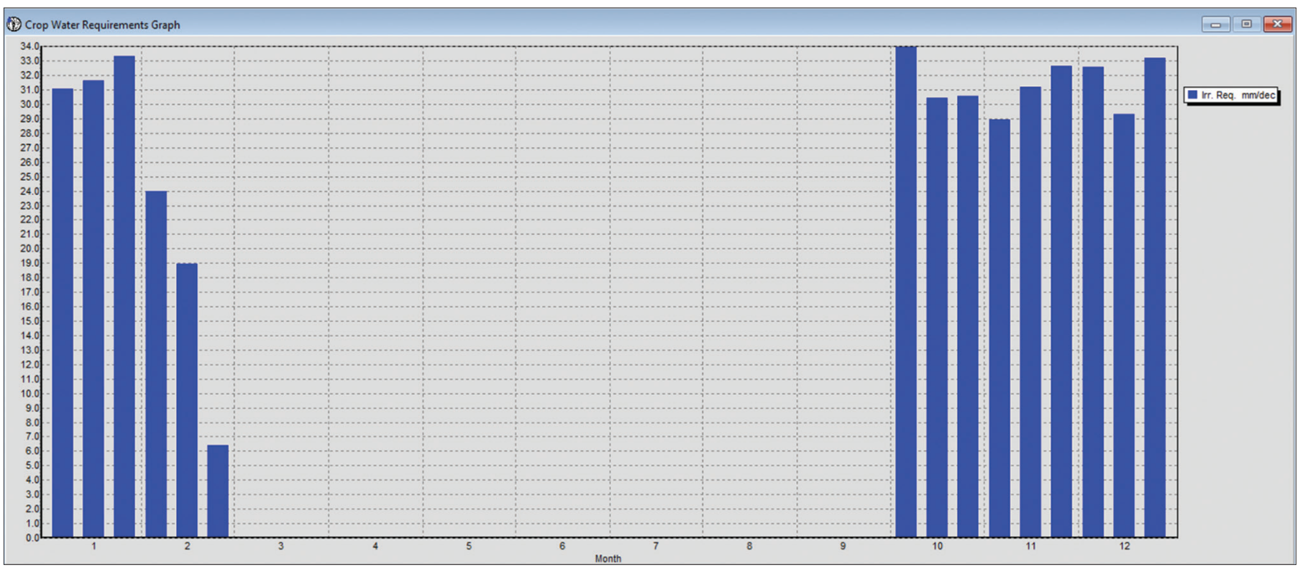

Figure 3: Tomato irrigation requirements

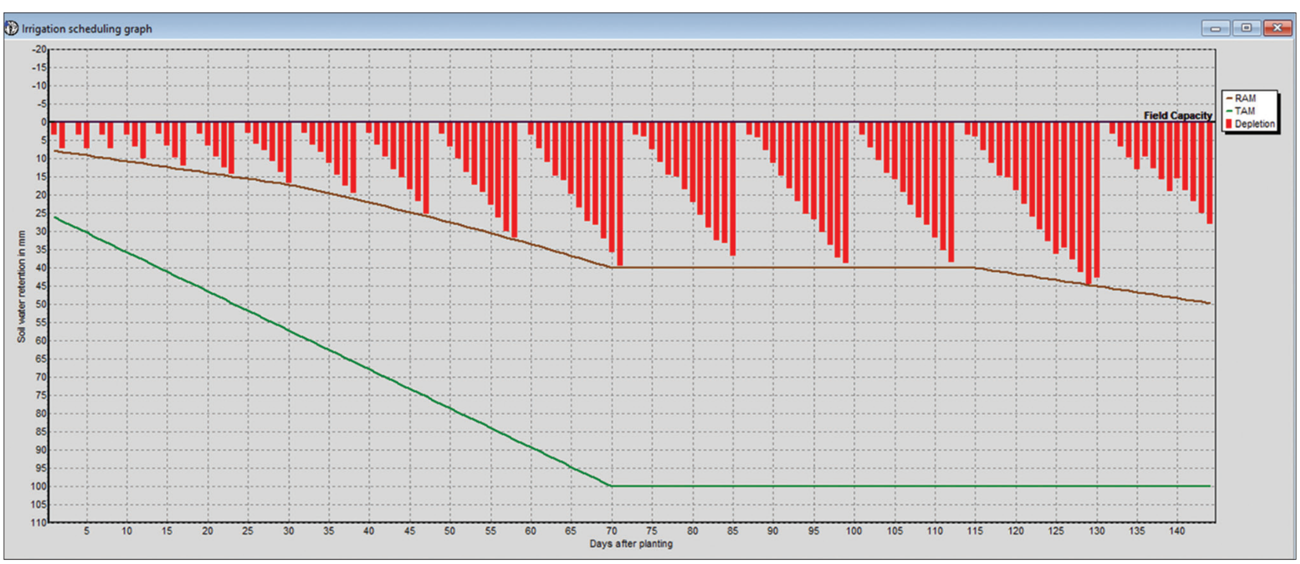

Figure 4: Tomato irrigation schedules

Figure 4 illustrated that the irrigation frequency to reach field capacity was high initially (Approximately day after two days) due to high ET_0 rates and low crop rooting depth. This frequency decreased to around 14 days (in the middle of the cultivation period) as evapotranspiration rates declined and crop rooting depth increased, with gradual rise in RAM and TAM, reaching the highest soil water retention of 40 mm and 100 mm, respectively, in the middle of the planting period (day 70 from the planting date). These results are consistent with Djaman *et al.* (2018), who note that water stress during critical growth stages can significantly impact crop productivity.

The calculated irrigation requirements and schedules demonstrate the effectiveness of using FAO-CROPWAT 8.0 and CLIMWAT 2.0 models for optimizing water management. Recent research supports the use of these models under various climatic conditions to enhance irrigation efficiency and crop yield.

CONCLUSION

The irrigation requirements and schedules for tomato cultivation in RAK developed by FAO-CROPWAT were tailored to the specific growth stages and soil characteristics of the crop according to RAK climatic conditions. The highest irrigation demand was recorded during the early and mid-growth stages, with a peak irrigation requirement of 34 mm/dec in October. The results showed that the initial high irrigation frequency was necessary, and as the crop matured, the irrigation frequency decreased.

The use of FAO-CROPWAT and CLIMWAT models proved effective in optimizing water management for tomato cultivation in the arid environment. These models facilitated the development of precise irrigation schedules that can significantly enhance water use efficiency and crop yield. The findings align with recent studies that advocate for the adoption of advanced irrigation modeling tools to support sustainable agricultural practices in regions facing water scarcity.

This research provided insights and practical guidelines for farmers, farm owners, and policymakers to improve irrigation practices, contributing to sustainable agriculture and food security in arid regions. The implementation of these findings can help mitigate the impacts of water scarcity and climate change on agriculture, ensuring the resilience and productivity of essential crops like tomatoes.

It is recommended to quantify the irrigation water requirement for tomatoes in other Emirates of the UAE; to investigate where the water requirements can be at minimal levels for sustainable tomato cultivation and food security purposes in the country. In addition, it is crucial to conduct awareness campaigns and workshops to communicate the research findings with the farmers, land owners, and decision-makers; to ensure the implementation of the best water management practices.

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