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Determination Irrigation Requirement for Some Vegetables and Fruits using FAO-CROPWAT model in in Southern Part of Iraq

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Abstract:

Crop water requirements (CWR) in semi-arid regions are critical in improving the efficiency of irrigation. The paper estimated the crop irrigation requirement for some vegetables and fruits in Basra, southern Iraq using CROPWAT model. The CROPWAT tool developed by FAO, it was applied in processing climate, soil, and crop data. The total amount of water that wheat, barley, and rice needed for irrigation in the study area was 99.1 mm, 103.1 mm, and 404.1 mm, respectively.Analysis entailed the assessment of the water demand and irrigation requirement (CWR & IR) of three plants in the order of Date Palm (1722.7, 1593) > Tomato (470.3, 415.4) > Pepper (427.9, 393.2) mm/dec. Estimation of crop water requirement involves a number of variables, including soil type, location, agricultural practices, air temperature, and effective rainfall. In addition, the demands of water are not constant at all stages of the crop. The findings showed that the frequency of irrigation of date palm, tomato, and pepper was high at first because of large values of ET 0 and shallow roots. This frequency reduced in the mid-season when there was a reduction in the evapotranspiration levels and expansion of root systems thus resulting in maximum water retention in the soil. The research encouraged better utilization of water by optimizing the irrigation schedule with the help of CROPWAT tool that will alleviate the adverse effects of improper irrigation like soil erosion, water shortage, and environmental problems in semi-arid areas like Basra Governorate, Iraq.

Keywords: ***Crop water requirement, Crop irrigation Scheduling, CROPWATmodel, Basrah***

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تحديد متطلبات الري لبعض الخضراوات والفواكه باستخدام نموذج FAO-CROPWAT في الجزء الجنوبي من العراق

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الخلاصة

يُعد فهم الاحتياجات المائية للمحاصيل (CWR)في المناطق شبه القاحلة أمرًا أساسيًا لتحسين ممارسات الري. وقد قدّرت هذه الورقة احتياجات مياه الري في البصرة، جنوب العراق، باستخدام نموذج .CROPWATحُسبت البيانات المناخية وبيانات المحاصيل والتربة باستخدام نموذج Cropwat، المستند إلى منظمة الأغذية والزراعة للأمم المتحدة (الفاو). كانت متطلبات المياه للمحصول ومتطلبات مياه الري (CWP& IRs)للمحاصيل بالترتيب التالي: التمر (1722.7، 1593) >الطماطم (470.3، 415.4)> الفلفل (427.9، 393.2) مم/ديس. تحديد متطلبات المحاصيل من المياه تتطلب المحاصيل كميات متفاوتة من متطلبات المياه بناءً على نوع التربة وموقعها وطريقة الزراعة ودرجة الحرارة والأمطار الفعالة وما إلى ذلك، كما أن إجمالي كمية المياه المطلوبة خلال دورة حياتها غير موزعة بالتساوي. كشفت الدراسة أن وتيرة الري لمحصول الطماطم والفلفل ومحصول التمر كانت عالية في البداية بسبب ارتفاع معدلات التبخر النتحي وانخفاض عمق تجذير المحصول. انخفض هذا المعدل في منتصف فترة الزراعة مع انخفاض معدلات التبخر النتحي وزيادة عمق تجذير المحصول، ليصل إلى أعلى معدل احتباس للماء في التربة في منتصف فترة الزراعة. عززت هذه الدراسة كفاءة استخدام المياه من خلال تحسين جداول الري المُستنبطة من نموذج CROPWAT، لأن الري غير الفعال يؤدي حتمًا إلى تدهور التربة وندرة المياه واختلال التوازن البيئي في المناطق شبه القاحلة مثل محافظة البصرة، العراق.

الكلمات المفتاحية: متطلبات المياه للمحاصيل، جدولة ري المحاصيل، نموذج CROPWAT، البصرة.العراق.

Introduction

The policymakers have increasingly focused on global warming and changes in climate patterns especially in the context of agricultural sectors (Mason, 2019). As highlighted by the United Nations World Water Development Report, the agricultural industry utilizes the highest proportion of global freshwater resources, accounting for nearly 70% of total withdrawals. Despite this, more than 60% of the water allocated for irrigation is reportedly lost, indicating that there are critical concerns about the effectiveness of current irrigation practices (Wu et al., 2022). The situation in Iraq is the country is facing serious water crisis and it is estimated that about 80 percent of the water used in Iraq is used in agriculture. Climate variability and increases in demands in other sectors are causing a sharp decrease in water availability in this sector (Molle et al., 2019).

The decline in water supply has also been contributed by the mega-projects of dams on rivers Tigris and Euphrates in Turkey which are yet to be completed and their effect on the water resources of the downstream countries is likely to be adversely affected particularly Iraq. The Iraqi Ministry of Water Resources has therefore laid a lot of focus on the assessment of irrigation management practices especially those that seek to improve efficiency through optimized irrigation systems.

Various studies have been done in Iraq to facilitate improved water management plans during water scarcity; among others are: (Nashaat & Al-Bahathy, 2022; Al-Bahathy et al., 2023; Al-Bahathy et al., 2024; Al-Janabi et al., 2025; Al-Bahathy & Nashaat, 2025; Al-Bahathy et al., 2025). CROPWAT and CLIMWAT are software used to create sustainable irrigation scheduling. especially as it has achieved significant water savings (43 – 45 %) (Champaneri et al., 2024)..

many researches worked to improve irrigation schedules for many crops, vegetables and fruits as Shahin (2024) who help in improve sustainability through application CROPWAT software to make optimal irrigation schedule for tomato. Furthermore, Mal & Sen (2025) utilized the CROPWAT software to determine the water needs of crops and to develop irrigation plans for tomato and soybean cultivation.

Research Objective

This research analyzed the methodologies employed to assess evapotranspiration and to synthesize the results pertaining to the water demands and irrigation planning for the selected crops (Solanum lycopersicum, Capsicum spp., and Phoenix dactylifera) within the Basra Governorate of southern Iraq, thereby aiming to reduce excessive water usage and promote sustainable irrigation practices.

Hypotheses of Research

The process of estimating crops water demand and Irrigation Scheduling by CROPWAT and CLIMWAT software tools help to reduce water consumption.

Method and Materials

Study Area

Basra Governorate lies in southern Iraq and shares borders with Maysan and Dhi Qar to the north, Muthanna to the west, Kuwait to the south, and Iran to the east. It accounts for 19,730 km², which is approximately 4.4% of Iraq's total land area. The climate in Basra is typified by arid desert conditions, marked by broad temperature fluctuations, minimal precipitation, and generally low humidity. The study area is geographically situated between longitudes 46°60′ to 48°60′ E and latitudes 29°13′ to 31°29′ N (Fig. 1).

Figure (1) shows Basra Governorate in southern Iraq.

Data Requirement

Climatic records spanning three decades were collected from the Basra Meteorological Station to support the estimation of irrigation requirements for various crops globally.

The CLIMWAT dataset provides information on seven primary climatic parameters, including monthly extremes in temperature, wind speed, mean relative humidity, duration of sunlight, total rainfall (in mm), and effective precipitation (in mm) (Clarke et al., 2001).

Crop-related data for tomato, pepper, and date palm were sourced from the FAO Manual and subsequently incorporated into the CROPWAT software. Soil characteristics used in the analysis were retrieved from the FAO CROPWAT 8.0 model (CROPWAT Software, FAO, Land and Water Division, 2018).

2.3. Evapotranspiration (ET)

The standard reference surface is modeled as a theoretical grass crop with a height of 0.12 meters and a uniform surface resistance of 70 s/m. The CROPWAT 8.0 software utilizes this reference to compute radiation and reference evapotranspiration (ET_0). For this purpose, the original Penman–Monteith formula was applied, as outlined in Equation.

$$\lambda\, ET\, (\quad =\Delta(Rn-G)+Pa\, Cp(es-ea)/ra)/(\Delta+\gamma(1+rs/ra)) \qquad (1)$$

where Rn denotes the net radiation, G represents the soil heat flux, and (es − ea) refers to the vapor pressure deficit in the atmosphere. Pa stands for the average air density under constant pressure, while Cp indicates the specific heat capacity of air. Δ signifies the gradient of the curve linking air temperature to saturation vapor pressure. γ is the psychrometric constant, and rs and ra correspond to surface and aerodynamic resistances, respectively.

$$ET0=(0.408\Delta(Rn-G)+\gamma 900/(T+273)u2(es-ea))/(\Delta+\gamma(1+0.34u2)) \qquad (2)$$

where ET_0 refers to reference evapotranspiration, given in millimeters per day. T is the mean daily air temperature measured at a height of 2 meters, and u_2 indicates wind speed observed at the same elevation (in m/s). *es* and *ea* represent the saturation and actual vapor pressures, respectively, expressed in kilopascals (kPa) (FAO, 2025).

Crop Water Requirement (CWR)

Crop water requirement is the amount of water required to replace losses of water due to evapotranspiration of a field that is under crops and is often expressed in millimeters per day.

CWR is calculated on the basis of crop evapotranspiration (ETc) that is calculated according to the formula offered by Pereira et al. (2015).

$$ETc = Kc\ ET0 \tag{3}$$

in which ETc is crop evapotranspiration (mm/day), ET 0 is reference evapotranspiration (mm/day) and Kc is crop coefficient.

Irrigation Water Requirement (IR)

CROPWAT model can be used to estimate the daily root zone water balance, the degree of depletion at the end of every day using the following equation.

$$Dr,i = Dr,i-1 - (P - ROi) - Ii - CRi + ETci + Dpi \tag{4}$$

where *Dr,i* is the amount of root zone water depletion measured at the end of day *i* (in mm), *Dr,i-1* is the level of moisture present in the root zone at the conclusion of the previous day (mm), *Pi* refers to the precipitation received on day *i* (mm), *ROi* denotes the runoff from the soil surface occurring on day *i* (mm), *Ii* is the net depth of irrigation water that infiltrates the soil on day *i* (mm), *Cri* represents the rise of groundwater into the root zone due to capillary action on day *i* (mm), *ETci* is the crop evapotranspiration on day *i* (mm), and *DPi* is the volume of water lost from the root zone on day *i* (mm)

Irrigation Timetable

Watering time scheduling helps in identifying the most appropriate time to irrigate crops and in so doing reduce wastage of water. CROPWAT model creates irrigation plans according to different conditions and situations of water availability (Allen et al., 2005).

Results and discussion

Reference evapotranspiration

As illustrated in Figure 2, the evapotranspiration results for Basra Governorate south of Iraq. It reached its peak in July (8,08 mm/day), and it's dropping in December (1.41 mm/day). A high evapotranspiration number signifies elevated evaporation due to elevated temperatures and maximum sunlight hours. Conversely, a low evapotranspiration value was due to lower temperatures, indicating lower crop water requirements (Agrawal et al, 2023). Evapotranspiration is intimately connected with the length and intensity of solar radiation. Ewaid et al. (2019), in their examination of specific crops which was tomato one them in Nasiriya Governorate, southern Iraq, it was revealed that the evaporation rate increased during summer.

It is clear that the combination of increasing temperatures and low humidity is what caused this. The opposite was noted in winter.

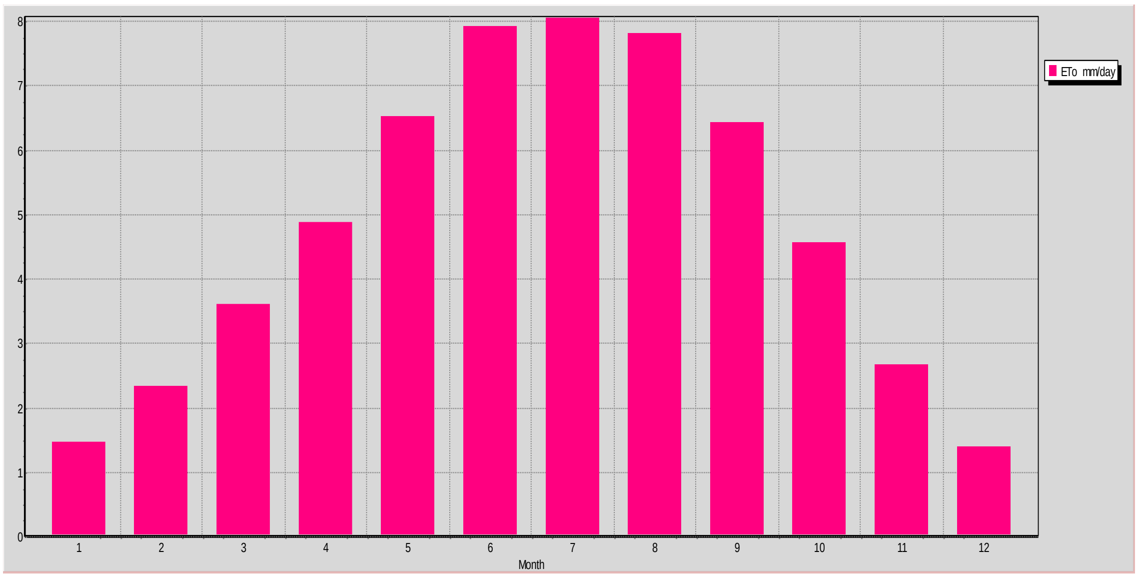
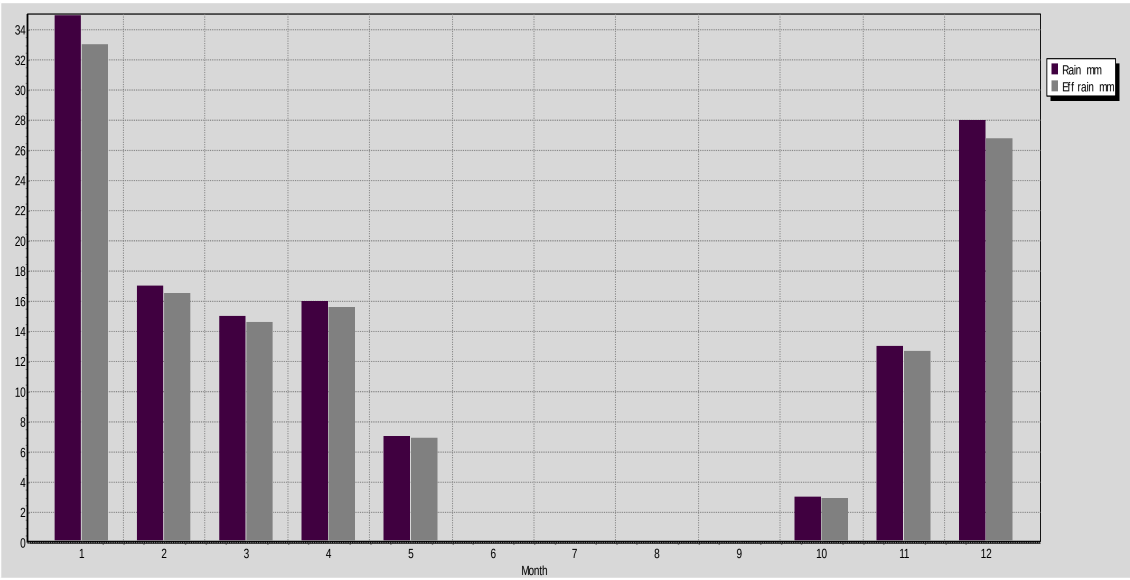


Figure 2, the evapotranspiration results for Basra Governorate south of Iraq Effective Rain

Effective rainfall

Figures (3) show the effective rainfall values were 33 in January and 0% were in June, July, August and September. The main features of rainfall values for crops were different temporally, which increased in winter and in contrast to other seasons (Zhu et al. 2025).



Figures (3) show the effective rainfall values for Basra Governorate south of Iraq

The crop water requirement for crops

The water demands and irrigation needs (CWP and IRs) of the crops studied were detailed in Tables (1, 2, & 3), and the examined crops are ranked as follows: Date Palm (1722.7, 1593) > Tomato (470.3, 415.4) > Pepper (427.9, 393.2) mm/dec.

The estimation of agricultural water demands is guided by the understanding that moisture needs vary based on several factors such as soil composition, geographical setting, and climate conditions. Moreover, the total moisture demand of a crop is not uniformly spread across its entire developmental stage. These results are consistent with the findings of Humphries et al. (2024). Likewise, similar outcomes were observed in the studies of Ewaid et al. (2019) and Maingi et al. (2020).

Table 1. Water demand for Tomato

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
August	Two	Init.	0.6	4.75	4.8	0	4.8
August	Three	Init.	0.6	4.45	49	0	49
September	One	Init.	0.6	4.14	41.4	0	41.4
September	Two	Dev.e	0.6	3.89	38.9	0	38.9
September	Three	Deve.	0.7	4.08	40.8	0.1	40.7
October	One	Deve.	0.84	4.36	43.6	0.5	43.1
October	Two	Deve.	0.98	4.46	44.6	0.7	43.9
October	Three	Mid.	1.11	4.38	48.2	1.9	46.4
November.	One	Mid.	1.15	3.8	38	3.1	35
November	Two	Mid.	1.15	3.08	30.8	4.1	26.7
November	Three	Mid.	1.15	2.59	25.9	5.7	20.2
December	One	Mid.	1.15	2.03	20.3	7.6	12.7
December	Two	Late.	1.1	1.45	14.5	9.3	5.2
December	Three	Late.	0.98	1.34	14.7	9.8	4.9
January	One	Late.	0.85	1.25	12.5	11	1.4
January	Two	Late.	0.79	1.17	1.2	1.2	1.2
					469.1	54.9	415.4

Table2.Crop water requirement for Pepper

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
August	Two	Init.	0.6	4.75	4.8	0	4.8
August	three	Init.	0.6	4.45	49	0	49
September	one	Init.	0.6	4.14	41.4	0	41.4
September	two	Dev.e	0.6	3.89	38.9	0	38.9
September.	Three	Deve.	0.7	4.05	40.5	0.1	40.4
October	One	Deve.	0.83	4.29	42.9	0.5	42.4
October	Two	Deve.	0.95	4.36	43.6	0.7	42.9
October	Three	Mid.	1.05	4.13	45.4	1.9	43.6
November	One	Mid.	1.05	3.48	34.8	3.1	31.8
November	Two	Mid.	1.05	2.82	28.2	4.1	24.1
November	Three	Mid.	1.05	2.38	23.8	5.7	18.1
December	One	Late.	1.02	1.81	18.1	7.6	10.5

December	Two	Late.	0.94	1.23	12.3	9.3	3.1
December	Three	Late.	0.89	1.22	2.4	1.8	2.4
.							
					426.1	34.7	393.2

Table 3. Crop water requirement for the Date Plame.

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
August	Two	Init.	0.98	7.74	7.7	0	69.7
August	Three	Init.	0.9	6.68	73.5	0	73.5
September	One	Init.	0.9	6.21	62.1	0	62.1
September	Two	Init.	0.9	5.79	57.9	0	57.9
September	Three	Init.	0.9	5.23	52.3	0.1	52.2
October	One	Init.	0.9	4.67	46.7	0.5	46.2
October	Two	Init.	0.9	4.11	41.1	0.7	40.4
October	Three	Init.	0.9	3.55	39	1.9	37.1
November	One	Init.	0.9	2.98	29.8	3.1	26.8
November	Two	Init.	0.9	2.42	24.2	4.1	20.1
November	Three	Init.	0.9	2.03	20.3	5.7	14.6
December	One	Init.	0.9	1.59	15.9	7.6	8.3
December	Two	Init.	0.9	1.18	11.8	9.3	2.5
December	Three	Init.	0.9	1.23	13.5	9.8	3.7
January	One	Deve.	0.9	1.31	13.1	11	2.1
January	Two	Deve.	0.92	1.36	13.6	12.1	1.5
January	Three	Deve.	0.94	1.66	18.2	9.9	8.3
February	One	Mid.	0.95	1.96	19.6	6.9	12.7
February	Two	Mid.	0.95	2.24	22.4	4.9	17.5
February	Three	Mid.	0.95	2.64	21.1	4.9	16.3
March	One	Mid.	0.95	3.04	30.4	5	25.4
March	Two	Mid.	0.95	3.45	34.5	4.8	29.7
March.	Three	Mid.	0.95	3.85	42.4	4.9	37.5
April	One	Mid.	0.95	4.26	42.6	5.4	37.2
April	Two	Mid.	0.95	4.66	46.6	5.6	41
April	Three	Mid.	0.95	5.19	51.9	4.5	47.4
May	One	Mid.	0.95	5.71	57.1	3.2	53.9
May	Two	Mid.	0.95	6.23	62.3	2.3	60.1
May	Three	Mid.	0.95	6.68	73.5	1.5	71.9
January	One	Mid.	0.95	7.19	71.9	0.1	71.7
January	Two	Mid.	0.95	7.66	76.6	0	76.6
June	Three	Mid.	0.95	7.68	76.8	0	76.8
July	One	Late.	0.97	7.76	77.6	0	77.6
July	Two	Late.	0.98	7.9	79	0	79
July	Three	Late.	0.98	7.82	86	0	86
August	One	Late.	0.98	7.8	78	0	78
August	Two	Late.	0.98	7.74	69.7	0	69.7
					1660.8	129.6	1593.1

Irrigation Scheduling

Tables (4, 5, and 6) revealed that the frequency of irrigation of tomato, pepper, and date palm was high in the beginning because the reference evapotranspiration (ET 0) was high and the rooting depths were shallow. This rate decreased in the middle of the growing season when the rate of evapotranspiration reduced and roots systems had been formed more and this is the time when the soil retained its maximum moisture content. These observations are consistent with those of Djaman et al. (2018), according to whom water demand did not change significantly during the same periods of growth.

Table 4. Irrigation schedules for tomato.

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
20-Aug.	1	Init.	zero	0.71	71	57	29.5	0	0	42.1	4.87
24-Aug	5	Init.	zero	1	100	37	22.2	0	0	31.7	0.92
28-Aug	9	Init.	zero	1	100	32	22.2	0	0	31.7	0.92
02-Sep	14	Init.	zero	1	100	34	27.1	0	0	38.7	0.9
08-Sep	20	Init.	zero	1	100	34	31.3	0	0	44.8	0.86
15-Sep	27	Init.	zero	1	100	33	35.3	0	0	50.5	0.83
23-Sep	35	Dev.	0.1	1	100	32	40.3	0	0	57.6	0.83
03-Oct	45	Dev.	0.2	1	100	36	52.2	0	0	74.6	0.86
15-Oct	57	Dev.	0	1	100	38	65.3	0	0	93.2	0.9
31-Oct	73	Mid.	0	1	100	41	81.3	0	0	116.2	0.84
30-Nov	103	Mid.	0	1	100	41	81.7	0	0	116.7	0.45
11-Jan	End	End.	0	1	0	11					

Table 5. Irrigation schedules for pepper

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
20-Aug	1	Init.	0	0.62	62	56	28.8	0	0	41.2	4.77
23-Aug	4	Init.	0	1	100	28	15.9	0	0	22.8	0.88
26-Aug	7	Init.	0	1	100	26	15.9	0	0	22.8	0.88
29-Aug	10	Init.	0	1	100	24	15.9	0	0	22.8	0.88
01-Sep	13	Init.	0	1	100	22	15.6	0	0	22.3	0.86
05-Sep	17	Init.	0	1	100	25	20	0	0	28.5	0.83
09-Sep	21	Init.	0	1	100	23	20	0	0	28.6	0.83
13-Sep	25	Init.	0	1	100	21	19.2	0	0	27.5	0.79
18-Sep	30	Init.	0	1	100	24	23.7	0	0	33.9	0.78
23-Sep	35	Dev.	0.1	1	100	22	24.1	0	0	34.5	0.8
29-Sep	41	Dev.	0	1	100	25	29.4	0	0	42.0	0.81
06-Oct	48	Dev.	0	1	100	27	35.5	0	0	50.8	0.84
14-Oct	56	Dev.	0	1	100	28	41	0	0	58.6	0.85
24-Oct	66	Mid.	0	1	100	30	48.1	0	0	68.8	0.8
07-Nov	80	Mid.	1.5	1	100	31	49.3	0	0	70.4	0.58
29-Nov	102	Mid.	0	1	100	31	50.1	0	0	71.5	0.38

22-Dec	End	End.	0	1	100	10					

Table 6. Irrigation schedules for Date Plame.

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
20-Aug	1	Init.	0	1	100	52	207.7	0	0	296.8	34.35
22-Sep	34	Init.	0	1	100	51	203.9	0	0	291.3	1.02
15-Nov	88	Init.	0	1	100	51	202.3	0	0	289	0.62
04-Apr	228	Mid.	0	1	100	50	200.3	0	0	286.1	0.24
16-May	270	Mid.	0	1	100	50	200.9	0	0	287.1	0.79
15-Jun	300	Mid.	0	1	100	52	206.9	0	0	295.6	1.14
11-Jul	326	End.	0	1	100	50	200.6	0	0	286.6	1.28
06-Aug	352	End.	0	1	100	51	203.9	0	0	291.3	1.3
19-Aug	End	End.	0	1	0	23					

Conclusion

The application of the FAO CROPWAT 8.0 model yielded notable outcomes. A high evapotranspiration number signifies elevated evaporation due to elevated temperatures and maximum sunlight hours. Conversely, a low evapotranspiration value was due to lower temperatures, indicating lower crop water requirements. The main features of rainfall values for crops were different temporally, which increased in winter and in contrast to other seasons, in their examination of specific crops in southern Iraq, it was revealed that the evaporation rate increased during summer. It is clear that the combination of increasing temperatures and low humidity is what caused this. The opposite was noted in winter. It was also evident that crop water demands and irrigation scheduling were adapted specifically to the unique characteristics of the research location, which relied on the seasonal and ecological context of Basra Governorate. The Crops water demand and irrigation requirements (CWP and IRs) were ranked in the following order: Date Palm > Tomato > Pepper (mm/dec). The analysis showed that tomato, pepper and date palm needed frequent irrigation at the beginning of the season because of high reference evapotranspiration (ET 0) and short roots. This frequency however declined at the middle of the growth period when there was less evapotranspiration and deeper root systems were established in the soil which led to maximum soil moisture retention at this stage. Such results will help in understanding the water requirements of major crops in Iraq in a better manner. This enhanced understanding can assist in better management and conservation of water resources and farmers can make informed decisions regarding the frequency and amount of irrigation using CWRs.

References

- Agrawal, A., Srivastava, P. K., Tripathi, V. K., Maurya, S., Sharma, R., & Dj, S. (2023). Future projections of crop water and irrigation water requirements using a bias-corrected regional climate model coupled with CROPWAT. *Journal of Water and Climate Change, 14*(4), 1147–1161. https://doi.org/10.2166/wcc.2023.325
- Al-Bahathy, I. A., Al-Janabi, Z. Z., Al-Ani, R. R., & Maktoof, A. A. (2023). Application of the water quality and water pollution indexes for assessing changes in water quality of the Tigris River in the south part of Iraq. *Ecological Engineering & Environmental Technology, 24*. https://doi.org/10.12912/27197050/165901
- Al-Bahathy, I. A., Al-Janabi, Z. Z., Al-Hassany, J. S., Majeed, O. S., & Naje, A. S. (2024). Environmental assessment of sediment quality for the Main Outfall Drain and Al-Sanaf Marsh. *Ecological Engineering & Environmental Technology, 25*. https://doi.org/10.12912/27197050/183645
- Al-Bahathy, I., & Nashaat, M. (2025). Impacts of Hindiya Barrage on the microcrustacean Cladocera along Euphrates River. *Egyptian Journal of Aquatic Biology and Fisheries*, *29*(3), 501–517. https://doi.org/10.21608/EJABF.2025.427687
- Al-Bahathy, I., Fairooz, N., Al-Ani, R., Al-Janabi, Z., & Majeed, O. (2025). Effect of Al-Dalmaj Marsh discharge canal on Copepoda community and water quality in the Main Outfall Drain River in Al-Qadisiya Governorate by using biodiversity and CCME-WQ indices. *Egyptian Journal of Aquatic Biology and Fisheries, 29*(3), 2839–2858. https://doi.org/10.21608/EJABF.2025.434032
- Al-Janabi, Z. Z., Al-Bahathy, I. A., Al-Hassany, J. S., Al-Ani, R. R., Naje, A. S., & Maktoof, A. A. (2025). Environmental impact of Al-Dalmaj Marsh discharge canal on the Main Outfall Drain River in the eastern part of Al-Qadisiya City and predicting the IQ-WQI with sensitivity analysis using BLR. *Nature Environment & Pollution Technology*, *24*(1).
- Champaneri, D. D., Desai, K. D., Ahlawat, T. R., Shrivastava, A., & Pampaniya, N. K. (2024). Assessment of CROPWAT 8.0 model accuracy under deficit irrigation scheduling: A sustainable path toward smart water supply. *Water Supply*, *24*(10), 3423–3437. https://doi.org/10.2166/ws.2024.184
- Clarke, D., Smith, M., & El-Askari, K. (2001). *CropWat for Windows: User guide*. University of Southampton.
- FAO, Land and Water Division. (2025). *CROPWAT software*. http://www.fao.org/land-water/databases-and-software/cropwat/en/

- Djaman, K., O'Neill, M., Owen, C. K., Smeal, D., Koudahe, K., West, M., Allen, S., Lombard, K., & Irmak, S. (2018). Crop evapotranspiration, irrigation water requirement and water productivity of maize from meteorological data under semiarid climate. *Water, 10*(4), 405. https://doi.org/10.3390/w10040405
- Ewaid, S. H., Abed, S. A., & Al-Ansari, N. (2019). Crop water requirements and irrigation schedules for some major crops in Southern Iraq. *Water, 11*(4), 756. https://doi.org/10.3390/w11040756
- Humphries, U. W., Waqas, M., Hlaing, P. T., Wangwongchai, A., & Dechpichai, P. (2024). Determination of crop water requirements and potential evapotranspiration for sustainable coffee farming in response to future climate change scenarios. *Smart Agricultural Technology, 8,* 100435. https://doi.org/10.1016/j.atech.2024.100435
- Maingi, S., Ndiiri, J., & Mati, B. (2020). Estimation of crop water requirements for garden pea, sweet pepper and tomato using the CROPWAT model in Maragua Watershed, Murang'a County, Kenya. *International Journal of Agricultural Science, 5*(1), 112–123.
- Mal, S., & Sen, S. (2025). Optimizing agricultural water use: Crop water requirement and irrigation scheduling of tomato & soybean using FAO CROPWAT 8.0 model in Chandrapur district, Maharashtra, India. *Next Research, 100529.* https://doi.org/10.1016/j.nexres.2025.100529
- Mason, B., Rufí-Salís, M., Parada, F., Gabarrell, X., & Gruden, C. (2019). Intelligent urban irrigation systems: Saving water and maintaining crop yields. *Agricultural Water Management*, *226*, 105812. https://doi.org/10.1016/j.agwat.2019.105812
- Molle, F., Sanchis-Ibor, C., & Avellà-Reus, L. (2019). *Irrigation in the Mediterranean*. Springer. https://doi.org/10.1007/978-3-030-03698-1
- Nashaat, M. R., & Al-Bahathy, I. A. A. (2022). Impact of Hindiya Dam on Copepoda diversity in Euphrates River, north of Babylon Province, Iraq. *Biological and Applied Environmental Research*, *6*(2), 121–143. https://doi.org/10.51304/baer.2022.6.2.121
- Pereira, L. S., Allen, R. G., Smith, M., & Raes, D. (2015). Crop evapotranspiration estimation with FAO-56: Past and future. *Agricultural Water Management, 147,* 4–20. https://doi.org/10.1016/j.agwat.2014.07.031
- Shahin, S. M. (2024). Determination of irrigation requirement for tomato using FAO-CROPWAT model in [incomplete reference—needs journal or publisher].
- Smith, M., Kivumbi, D., & Heng, L. K. (2002). Use of the FAO CROPWAT model in deficit irrigation studies. In *Deficit irrigation practices* (pp. 17–32). FAO.

- Wu, Y., Yan, S., Fan, J., Zhang, F., Zhao, W., Zheng, J., … & Wu, L. (2022). Combined effects of irrigation level and fertilization practice on yield, economic benefit and water-nitrogen use efficiency of drip-irrigated greenhouse tomato. *Agricultural Water Management, 262*, 107401. https://doi.org/10.1016/j.agwat.2021.107401
- Zhu, S., Tong, W., Li, H., Li, K., Xu, W., & Liang, B. (2025). Temporal variations in rice water requirements and the impact of effective rainfall on irrigation demand: Strategies for sustainable rice cultivation. *Water*, *17*(5), 656. https://doi.org/10.3390/w17050656