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Study on Major Crops Water Demand and Irrigation Scheduling in Basrah Governorate Based on CROPWAT Model

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Abstract:

Scarcity of water in Iraq represents a major environmental challenge, driven by factors such as global climate change and the blocking of river flows by dams in upstream countries. Recognizing crop water requirements (CWR) in semi-arid regions is critical for improving irrigation planning, scheduling, and optimizing water use. This study calculated the irrigation water demands for the crops were ranked as follows: Rice (1475.8 mm/decade) > Maize (439.3 mm/decade) > Wheat (103.9 mm/decade). Irrigation scheduling was calculated as two events for wheat, three for maize, and sixteen for rice. Rice, as the main summer crop, required greater quantities of water and more frequent irrigation compared to maize and wheat. These results highlight that rice needed much more irrigation due to limited rainfall during its growing period. Moreover, the plants cultivated during warmer periods require increased irrigation supply too, which mean it is negatively associated with reduced rainfall and positively with higher evapotranspiration rates. The research emphasizes the importance of employing advanced scientific tools like the CROPWAT and CLIMWAT models to achieve precise irrigation scheduling for farmers. Moreover, it provides valuable insights for policymakers, farmers and water resource managers to develop water management strategies. in Iraq

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

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دراسة متطلبات المياه وجداول الري المحسوبة بواسطة برنامج CROPWAT للمحاصيل الرئيسية في محافظة البصرة

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الخلاصة

يشكل نقص المياه في العراق تحديًا بيئيًا كبيرًا ناجمًا عن تغير المناخ وبناء السدود على أنهار العراق في الدول المجاورة. ويُعد فهم احتياجات المحاصيل المائية (CWR) في المناطق شبه القاحلة أمرًا أساسيًا لتحسين ممارسات الري، وجداول الري، وكفاءة استخدام المياه. قامت هذه الدراسة بحساب احتياجات المحاصيل من مياه الري. وقد صُنِف بالترتيب التالي: الأرز (1475.8 مم / ديسيمتر) < الذرة (439.3 مم / ديسيمتر) < القمح (103.9 مم / ديسيمتر). وكان جدول الري عبارة عن مرتين للقمح وثلاثة للذرة وستة عشر للأرز. أن الأرز، باعتباره المحصول الصيفي الرئيسي، يحتاج إلى كميات أكبر من المياه وري أكثر تواترًا مقارنةً بالذرة والقمح، وحاجة الأرز إلى ري أكثر بكثير بسبب قلة هطول الأمطار خلال فترة نموه. و أن النباتات المزروعة خلال الفترات الدافئة تتطلب زيادة في إمدادات الري، وهو ما يرتبط سلبًا بانخفاض هطول الأمطار، ويرتبط إيجابًا بارتفاع معدلات التبخر والنتح. ويؤكد البحث على أهمية استخدام الأدوات العلمية المتطورة مثل نموذجي CROPWAT و CLIMWAT لتحقيق جدولة الري الدقيقة للمزارعين. علاوة على ذلك، فهو يوفر رؤية قيمة لصناع السياسات والمزارعين ومديري الموارد المائية لتطوير استراتيجيات إدارة المياه بشكل مستدام في العراق.

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

Introduction

Climate change presents challenges to humanity that affect agriculture, services, and industry (Waqas et al., 2024). First and foremost, limited water availability poses a worldwide problem, especially in dry and sub-humid nations where a shortage of water resources seriously impairs industrial growth, ecological restoration, and agricultural output (Ingrao et al., 2023). The prolonged drought, reduced reservoir storage, river siltation, and limits on water access due to competing demands underscore the importance of careful water management to ensure sustainable agricultural growth. The main constraint on agricultural output and diversification is water. Agrarian irrigation uses more than 80% of water resources. Therefore, maximizing water efficiency in farming should be prioritized (Biswas et al., 2025).

Soil water makes up only a small fraction (0.15%) of global freshwater resources. Soil moisture is vital for crop production and maintaining plant development. Management of soil water is critical to numerous hydrological, environmental, and biogeochemical processes. Effective planning needs reliable data on evapotranspiration, crop water demand, and net irrigation needs (Gaddikeri et al., 2025). Crop water requirements, and net irrigation schedules mad by CROPWAT model is essential for effective planning of water resources sustainability (Khan et al., 2019).

The water issue is critical in environmental sustainability; therefore, many researchers have worked on this topic, such as: Nashaat and Al-Bahathy (2022); Al-Bahathy and colleagues (2023); Al-Bahathy et al. (2024); Al-Janabi et al. (2025); Al-Bahathy with Nashaat (2025). Moreover, many international researchers have applied Cropwat model for create optimal irrigation scheduling for some crops; for example, Dong et al. (2024) highlighted their role in

sustainability by modeling water needs for crops like soybean in Heilongjiang, China, using CROPWAT. Additionally, studies such as Deveci et al. (2025) employed CROPWAT to calculate crop water needs and plan irrigation schedules for wheat and canola in Turkey.

Research Objectives

- 1- This study is intended as supporting data, recognizing that local variables such as soil properties, weather patterns, and other specific conditions must be accounted for when planning irrigation. It is important to gather weather and evapotranspiration data to establish reliable guidelines for water management, which is critical for sustainable on-farm practices and water allocation.
- 2-Using CROPWAT and CLIMWAT software tools that estimate agricultural water requirements using climatic, crop, and soil information.
- 3-. Finally, the aims of this study are to outline and explain the approaches for measuring evapotranspiration in the research area, as well as to present the results regarding water demand and irrigation plans for the selected crops (wheat, corn, and rice) in Basrah Governorate, southern Iraq, to help reduce water consumption.

Hypotheses of Research

Using CROPWAT and CLIMWAT software tools to estimate crops water demand and Irrigation Scheduling help to reduce water consumption by taking into account the region's weather conditions, soil type, and crop type using a global system that includes FAO-CROPWAT Model.

Method and Materials

Study Area

he research area is located in southern Iraq, positioned between 46°60' to 48°60' E longitude and 29°13' to 31°29' N latitude, covering an overall area of 19,070 km² (see Fig. 1). The district lies in southern Iraq. It is among Iraq's key farming zones, cultivating crops like wheat, maize, and rice, among others. The region's average population growth is around 3.6% of the national population. Basrah, which is experiencing a severe environmental crisis marked by extreme heat. Mean annual evaporation exceeds 2450 mm/year while average yearly rainfall remains under 100 mm. Water salinity is high, and temperatures can surpass 53 °C (Meteorology 2025). Salinity levels in the Shatt al-Arab approach those of seawater, contributing to agricultural decline as the region faces water scarcity and frequent crop failures. Basrah is located on the western bank of the Shatt al-Arab, a waterway formed where the Tigris and Euphrates meet. The

surrounding landscape is flat and heavily cut by small streams and drainage channels. Shown in Figure 1.



Figure 1: shows Basrah Governorate south Iraq.

CROPWAT 8.0

The methodology relied on the CROPWAT 8.0 tool released by FAO (2025). This software enables the calculation of both basic outputs like ET_0 and more advanced results such as ET_c , irrigation requirements, and even simulations for irrigation schedules, yield reductions, or runoff generated during irrigation events.

The required input includes (i) climate and rainfall data, (ii) crop details, and (iii) soil properties. Many standard values are available through CLIMWAT 8.0 (linked with CROPWAT)—for example, climatic parameters, or from reference tables that include typical crop coefficients, stage durations, maximum plant height, and rooting depth.

Climatic information for thirty years (1970–2000) were existed in the CLIMWAT contains seven parameters with the coordinates the location. These parameters are monthly temperature ($^{\circ}\text{C}$), wind speed (km/h), mean relative humidity (%), sunshine hours (h), rainfall data (mm), and

effective rainfall (mm) as showed in website (CROPWAT Software, FAO, Land and Water Division., 2025).

Evapotranspiration (ET)

Climatic parameters (air temperature, humidity, wind velocity, sunshine hours, and rainfall), combined with site characteristics (elevation above sea level, latitude, and longitude), are used by CROPWAT 8.0 to estimate radiation and ET_0 . The Penman–Monteith approach was modified for improved practicality and simpler, broader application.

$$\lambda ET = \frac{\Delta(R_n - G) + P_a C_p (e_s - e_a) / r_a}{\Delta + \gamma(1 + r_s / r_a)}$$

where R_n stands for net energy radiation, G indicates soil heat transfer, $(e_s - e_a)$ reflects the difference in vapor pressure in the air, P_a is the average air mass density at standard atmospheric pressure, C_p is the specific thermal capacity for air, Δ represents the gradient of the curve that links saturation vapor pressure to temperature, γ is the psychrometric coefficient, and r_s and r_a denote the surface and aerodynamic resistance values, respectively.

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)} \quad (1)$$

where ET_0 indicates the standard evapotranspiration (mm/day), T is the mean daily air temperature ($^{\circ}\text{C}$) measured at 2 m above ground, u_2 refers to wind speed at 2 m elevation (m s^{-1}), and e_s and e_a denote the saturated and actual vapor pressures (kPa), respectively (FAO, 2025).

2.4. Crop Water Requirement (CWR)

The crop water demand indicates the volume (or depth) of water needed to compensate for losses through evaporative processes (ET). Various crop-specific parameters are needed for calculation, such as sowing and harvesting dates, crop coefficient (K_c) factors, duration of growth periods, plant height, root zone depth, critical depletion thresholds, and yield sensitivity. These elements help calculate ET_c and the crop water demand (CWR). The calculation of ET_c is given in Equation (2):

$$ET_c = K_c ET_0$$

where ET_c represents the crop's evapotranspiration rate (mm/day), ET_0 signifies the baseline evapotranspiration (mm/day), and K_c is the related crop factor.

Irrigation Water Requirement (IR)

The CROPWAT model calculates the daily moisture balance in the root zone by determining the depletion at day's end using the formula:

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

where Dr,i indicates the moisture level in the root zone on day i (mm), $Dr,i-1$ is the water content from the previous day (mm), Pi refers to rainfall on day i (mm), ROi is the surface runoff (mm), Ii is the irrigation volume entering the soil on day i (mm), CRi is the upward movement of groundwater (mm), $ETci$ is crop evapotranspiration on day i (mm), and DPi represents water losses through deep percolation from the root zone on day i (mm).

Irrigation Schedule

Planning irrigation assists in determining optimal timing for water application. The CROPWAT tool generates irrigation timetables tailored to varying conditions and water availability (Allen et al., 2005).

Results and discussion

The monthly averages of ET_0 reached their highest value of 8.08 mm day⁻¹ in July. A wind speed of 233 km day⁻¹ was recorded, exceeding the average observed during the study period, which was 205 km day⁻¹, as indicated in Table 1. Conversely, the minimum ET_0 of 1.41 mm day⁻¹ was noted in December, coinciding with a lower solar radiation value of 10.7 MJ m⁻² day⁻¹, which is below the average for the study period of 18.5 MJ m⁻² day⁻¹, as shown in Table 2. This reduced radiation can be attributed to the climatic conditions in Iraq, characterized by cloudiness and a high relative humidity of 95%. Some researchers have indicated that wind speed and solar radiation are the climatic variables that most significantly affect ET_0 (Gabr, 2022). Other studies have reached similar conclusions, including those by Gaddikeri et al. (2024).

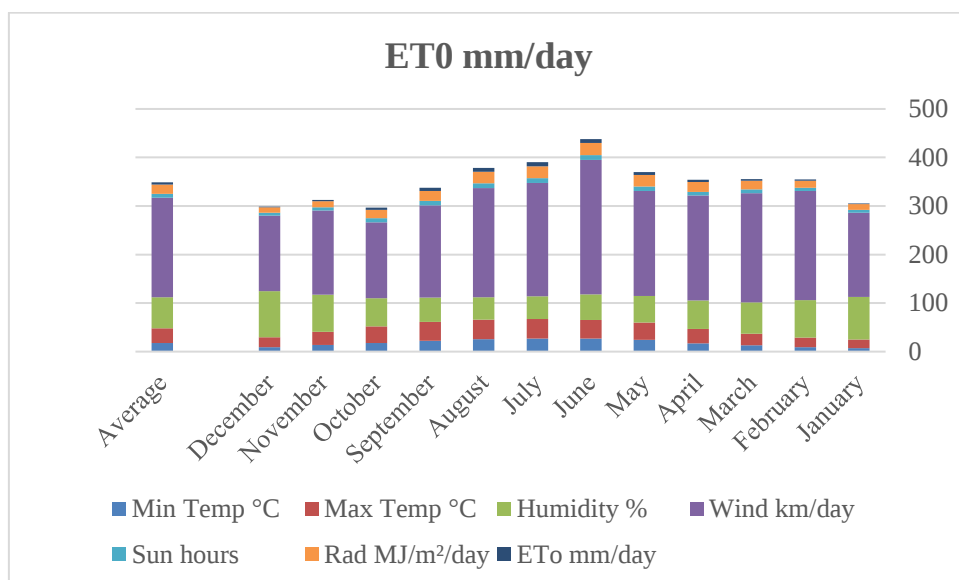


Figure 2: dhow the monthly averages of ET0.

Tables 1, 2, and 3 illustrate the effective rainfall values utilized by wheat, maize, and rice, respectively. The average effective rainfall percentages were 85%, 25.5%, and 6.9%. The primary characteristics of the rainfall values for these crops varied temporally and showed a positive correlation with heat and rainfall amounts (Zhu et al., 2025).

Crop Water Requirements for Wheat, Maize, and Rice

Assessing Crop Water Requirements: Different crops need varying water quantities depending on soil characteristics, geographic area, farming practices, temperature, effective rainfall, and other factors. Additionally, water use across a crop's lifecycle is not uniform. The irrigation water requirements (IRs) for the crops were in the following order: Rice (1475.8 mm/dec) > Maize(439.3 mm/dec) > Wheat (103.9 mm/dec) according to Tables (1,2 & 3).

The data indicates that the irrigation needs for rice (summer crops) are greater compared to other season crops, such as wheat and barley. The data presented in tables (1,2 and 3) indicate that crops cultivated during the hot season necessitate increased water, which is negatively connected with reduced rainfall and positively with elevated Etc. Conversely, in the cold season, heavy rainfall corresponds with decreased ETc. Similarity, these findings agreed with. such as Ewaid et al. (2019) who investigated the crops in south of Iraq. Also, Gaddikeri et al. (2024) who studied some crops in Madhya Pradesh's agro-climatic regions in India.

Table 1: Crop water requirement for wheat.

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
October	1	Init	0.3	1.56	1.6	0	1.6
October	2	Init	0.3	1.37	13.7	0.7	13

October	3	Init	0.3	1.18	13	1.9	11.1
November	1	Deve	0.31	1.02	10.2	3.1	7.1
November	2	Deve	0.51	1.37	13.7	4.1	9.6
November	3	Deve	0.79	1.78	17.8	5.7	12.1
December	1	Mid	1.06	1.87	18.7	7.6	11.1
November	2	Mid	1.14	1.49	14.9	9.3	5.6
November	3	Mid	1.14	1.55	17.1	9.8	7.2
January	1	Mid	1.14	1.66	16.6	11	5.5
January	2	Late	1.12	1.66	16.6	12.1	4.5
January	3	Late	0.89	1.57	17.2	9.9	7.3
February	1	Late	0.59	1.22	12.2	6.9	5.3
February	2	Late	0.37	0.87	5.2	2.9	2.8
Average							
					188.3	85	103.9

Table 2: Crop water requirement for maize.

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
August	1	Init	0.3	2.39	2.4	0	2.4
August	2	Init	0.3	2.38	23.8	0	23.8
August	3	Deve	0.31	2.28	25.1	0	25.1
September	1	Deve	0.5	3.42	34.2	0	34.2
September	2	Deve	0.76	4.87	48.7	0	48.7
September	3	Deve	1.02	5.91	59.1	0.1	59
October	1	Mid	1.21	6.26	62.6	0.5	62.1
October	2	Mid	1.21	5.54	55.4	0.7	54.7
October	3	Mid	1.21	4.78	52.6	1.9	50.7
November	1	Mid	1.21	4.02	40.2	3.1	37.1
November	2	Late	1.11	2.98	29.8	4.1	25.7
November	3	Late	0.82	1.86	18.6	5.7	12.9
December	1	Late	0.54	0.95	9.5	7.6	1.9
December	2	Late	0.36	0.48	1	1.9	1
Average							
					462.9	25.5	439.3

Table 3: Rice crop water requirement.

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
May	1	Nurs	1.2	0.72	6.5	2.9	3.2
May	2	Nurs/LPr	1.08	6.33	63.3	2.3	153.6
May	3	Nurs/LPr	1.06	7.44	81.9	1.5	262
June	1	Init	1.1	8.28	82.8	0.1	82.7
June	2	Init	1.1	8.84	88.4	0	88.4
June	3	Deve	1.12	9.03	90.3	0	90.3

July	1	Deve	1.16	9.32	93.2	0	93.2
July	2	Deve	1.2	9.7	97	0	97
July	3	Mid	1.22	9.74	107.1	0	107.1
August	1	Mid	1.22	9.71	97.1	0	97.1
August	2	Mid	1.22	9.65	96.5	0	96.5
August	3	Late	1.22	9.04	99.4	0	99.4
September	1	Late	1.18	8.16	81.6	0	81.6
September	2	Late	1.13	7.31	73.1	0	73.1
September	3	Late	1.09	6.35	50.8	0.1	50.6
Average							
					1208.9	6.9	1475.8

3.2. Irrigation Scheduling

Understanding irrigation planning enhances field management by regulating the quantity, timing, and application rate of irrigation in an organized and effective way. Tables 5, 6, and 7 show that wheat has two irrigation cycles, maize has three, and rice requires sixteen.

The findings of this study indicated that rice required more irrigation due to the lack of rain during its planting season. This study indicates that plants cultivated during warmer periods require increased irrigation supply, which is negatively associated with reduced rainfall and positively with higher evapotranspiration rates.

This study demonstrated that the irrigation requirements for each crop were reduced during the initial stage and then rose during the developmental period. Furthermore, it remained rather stable, peaking during the intermediate phase, while declining in the later phase due to the necessity for dry land to enable harvesting. Tables (4, 5 & 6) indicated that the rice irrigation schedules were more frequent than the other two crops due to a lack of rain during their planting season in summer

Similarity, these findings agreed with. other authors such as Chandra & Kumari (2021) who conducted a study to investigate the crops water requirement for the wheat. Maize and rice in Bihar, India.

Table 4: Irrigation schedules for wheat.

Date	Da y	Stag e	Rai n mm	Ks fract .	Eta	Dep l %	Net Irr mm	Defici t mm	Los s mm	Gr. Irr mm	Flow l/s/ha
12- October	3	Init	zero	1	100 %	56	38.9	zero	zero	55.5	2.14
25- Novembe r	47	Dev	zero	1	100 %	55	111.1	zero	zero	158. 8	0.42
16- February	End	End	zero	1	100 %	29					

Table 5: Irrigation schedules for maize.

Date	Day	Stage	Rain mm	Ks frac t.	Eta	Puddle state	Percol. mm	Depl.S M mm	Net Gift mm	Loss mm	Depl.S AT mm
24-May	-7	PreP u	zero	1	100 %	Prep	zero	18	40	zero	40
27-May	-4	Pud dl	0.8	1	100 %	Prep	zero	3	90	zero	40
30-May	-1	Pud dl	zero	1	100 %	OK	7.7	zero	63.5	zero	13.5
03-June	3	Init	0.1	1	100 %	OK	3.1	zero	96.3	zero	-3.7
12-Jun	12	Init	zero	1	100 %	OK	3.1	zero	103. 5	zero	3.5
20-June	20	Init	zero	1	100 %	OK	3.1	zero	95.5	zero	-4.5
28-June	28	Dev	zero	1	100 %	OK	3.1	zero	97.1	zero	-2.9
06-July	36	Dev	zero	1	100 %	OK	3.1	zero	98.9	zero	-1.1
14-July	44	Dev	zero	1	100 %	OK	3.1	zero	101	zero	1
22-July	52	Mid	zero	1	100 %	OK	3.1	zero	102. 5	zero	2.5
30-July	60	Mid	zero	1	100 %	OK	3.1	zero	102. 8	zero	2.8
07-August	68	Mid	zero	1	100 %	OK	3.1	zero	102. 6	zero	2.6
15-August	76	Mid	zero	1	100 %	OK	3.1	zero	102. 2	zero	2.2
23-August	84	Mid	zero	1	100 %	OK	3.1	zero	100. 2	zero	0.2
31-August	92	End	zero	1	100 %	OK	3.1	zero	97.2	zero	-2.8

09-Sepember	101	End	zero	1	100%	OK	3.1	zero	101.4	zero	1.4
19-Sepember	111	End	zero	1	100%	OK	3.1	zero	105	zero	5
28-Sepember	End	End	zero	1	zero	OK	zero	zero			

Table 6: Irrigation schedules for maize.

Date	Day	Stage	Rain	Ks	Eta	Puddl	Percol.	Depl.SM	Net Gift	Loss	Depl.SAT
			mm	fract.		state	mm	mm	mm	mm	mm
01-May	-19	PrePu	zero	0.9	90%	Prep	zero	42	92	zero	40
14-May	-6	PrePu	zero	1	100%	Prep	zero 17		40	zero	40
16-May	-4	Puddl	zero	1	100%	Prep	2.8	1	90	zero	40
19-May	-1	Puddl	zero	1	100%	OK	7.7	zero	59.3	zero	9.3
24-May	4	Init	zero	1	100%	OK	3.1	zero	104.2	zero	4.2
02-June	13	Init	zero	1	100%	OK	3.1	zero	97.6	zero	-2.4
11-June	22	Dev	zero	1	100%	OK	3.1	zero	103.1	zero	3.1
19-June	30	Dev	zero	1	100%	OK	3.1	zero	97.1	Zero	-2.9
27-June	38	Dev	zero	1	100%	OK	3.1	zero	99.4	zero	-0.6
05-July	46	Dev	zero	1	100%	OK	3.1	zero	101.2	zero	1.2
13-July	54	Mid	zero	1	100%	OK	3.1	zero	102.6	zero	2.6
21-July	62	Mid	zero	1	100%	OK	3.1	zero	103.3	zero	3.3
29-July	70	Mid	zero	1	100%	OK	3.1	zero	102.6	zero	2.6
06-August	78	Mid	zero	1	100%	OK	3.1	zero	102.4	zero	2.4
14-August	86	Mid	zero	1	100%	OK	3.1	zero	102.1	zero	2.1
22-August	94	End	zero	1	100%	OK	3.1	zero	100	zero	0
31-August	103	End	zero	1	100%	OK	3.1	zero	106.6	zero	6.6
09-September	112	End	zero	1	100%	OK	3.1	zero	98	zero	-2
17-September	End	End	zero	1	zero	OK	zero	zero			

Conclusion

Applying the FAO CROPWAT 8.0 tool yielded notable findings. The analysis showed that water needs and irrigation plans varied according to the local area's seasonal and environmental

conditions. Rice, as the main summer crop, required greater quantities of water and more frequent irrigation compared to maize and wheat, following the sequence rice > maize > wheat. These insights will therefore support better management of water resources and enhance productivity through policies informed by this research. The application of scientific tools like CROPWAT and CLIMWAT enables precise evaluation of crop water requirements. The findings from this research can assist planners in developing strategies to conserve water and serve as guidance for growers in determining irrigation amounts and scheduling for these crops. This study indicates that plants cultivated during warmer periods require increased irrigation supply, which is negatively associated with reduced rainfall and higher evapotranspiration rates. The study's results suggested that rice needed more frequent irrigation compared to the other two crops due to limited rainfall during its growth period. The research emphasizes the importance of using advanced instruments such as CROPWAT along with CLIMWAT for assessing crop water needs, irrigation water requirements, and scheduling with enhanced accuracy for agricultural producers globally, such as those in Iraq.

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