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Crop Water Requirements and Irrigation Schedules for Some Major Crops in Southern Iraq

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Abstract: The climate of Iraq is of the subtropical semi-dry type; however, the country was rich in water resources until a few decades ago. Climate change and the construction of many dams on the Tigris and Euphrates rivers in the neighboring countries have caused water shortages and poor water quality. Now, there is a need to decrease consumption, improve management of water resources, and determine the water requirements of the major crops because agriculture is the first consumer of water in Iraq. The Food and Agriculture Organization (FAO) CROPWAT 8.0 simulation software and the CLIMWAT 2.0 tool attached to it have been used in this research for Dhi-Qar Province in southern Iraq to find the crop water requirements (CWRs) and irrigation schedules for some major crops. The CROPWAT Penman–Monteith method was used to calculate the reference crop evapotranspiration (ET_0) and the United States Department of Agriculture (USDA) soil conservation (S.C.) method was used to estimate the effective rainfall. The study results showed that ET_0 varied from 2.18 to 10.5 mm/day and the effective rainfall varied from 0.0 to 23.1 mm. The irrigation requirements were 1142, 203.2, 844.8, and 1180 mm/dec for wheat, barley, white corn, and tomatoes, respectively. There is a higher water demand for crops during the dry seasons (summer and autumn) and a lower demand during the wet seasons (winter and spring). The total gross irrigation and the total net irrigation were 343.8 mm and 240.7 mm for wheat, 175.2 mm and 122.6 mm for barley, 343.8 mm and 240.7 mm for white corn, and 203.3 mm and 142.3 mm for tomatoes. This study proved that the CROPWAT model is useful for calculating the crop irrigation needs for the proper management of water resources.

Keywords: Iraq; CROPWAT; irrigation schedules; crop water requirement

1. Introduction

Iraq has been known as the land of the two rivers (Mesopotamia) since ancient times. Its abundant fertile land, fresh water, and varying climate have contributed to the creation of a deep-rooted civilization that had prospered for thousands of years [1].

Iraq is relatively well supplied with water in comparison to its Middle East neighbors. However, only one-third of the annual available irrigation water supply actually reaches crops. Water reaching farmers' fields often does not arrive in a timely manner or in optimum amounts for all farms [2]. Water is often poorly distributed to the flood irrigated lands in Iraq because of inadequate leveling, lack of knowledge, and poor water management practices [1].

Iraqi water resources are inefficiently managed especially when it comes to irrigation. Previously, this issue was not a real problem because of the abundance of water in the Tigris and Euphrates rivers with relatively moderate rainfall levels. However, with the recent water scarcity crisis, low rainfall levels, and decrease in the main rivers' discharge, there has been a need to modernize irrigation systems [3,4].

Agriculture is the main consumer of water in Iraq, and the irrigation systems require modernization and good management by evaluating water system prerequisites precisely. It is important to know the crop water requirements (CWRs) and irrigation scheduling to take care of the irrigation demand [5,6].

Software modeling by programs like AQUACROP and CROPWAT 8.0 is a significant practice used by scientists for the assessment of crop evapotranspiration, CWR, and irrigation scheduling. These software programs were developed by the Food and Agriculture Organization (FAO) as tools to assist irrigation engineers and agronomists in performing the usual calculations for water irrigation studies and mainly in the management and design of irrigation schemes [7]. In the present study, the irrigation water requirements and irrigation scheduling of some selected crops (wheat, barley, white corn, and tomatoes) in Dhi-Qar Province, southern Iraq were studied using the CROPWAT model.

2. Materials and Methods

2.1. Study Area

Dhi-Qar Province is located about 370 km southeast of Baghdad between latitude 31°14′ N and longitude 46°19′ E. It has an area of 13,552 km^2, with an estimated population of 1,450,200 people, and it borders the provinces of Basrah, Missan, Muthanna, Qadissiya, and Wassit (Figure 1). Nasiriya, the capital city of this province, has a meteorological station at latitude 31.08° N and longitude 46.23° E [8,9].

The Euphrates and Al-Gharraf (branch of Tigris) rivers in addition to the marshes cross the province. Dhi-Qar has a dry desert climate of long and hot summers, with average high temperatures reaching 50 °C, whereas winter is short and mild. Rain falls between November and April, and averages 100 mm annually [10]. The arable area is about 1,822,870 dunams, and the cultivated area is 620,942 dunams (1 dunam = 2500 m^2) [11].

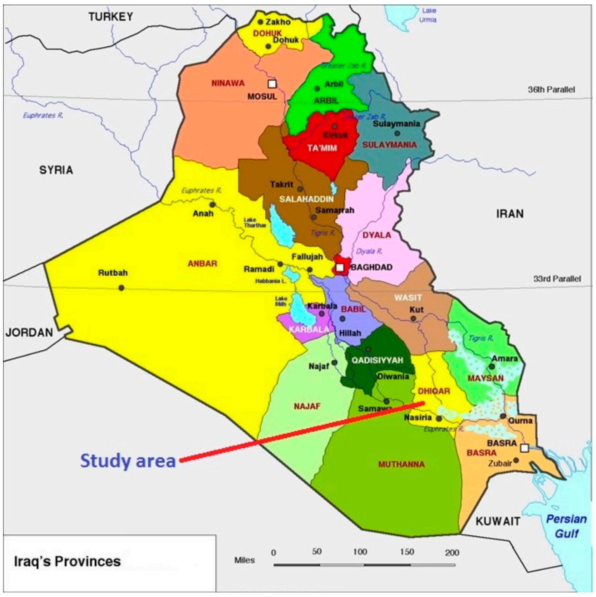

Figure 1. Dhi-Qar Province and its location in southern Iraq.

2.2. CROPWAT 8.0 Model Description

CROPWAT 8.0 is a decision-support computer program based on a number of equations, developed by the FAO to calculate reference evapotranspiration (ET$_0$), crop water requirement (CWR), irrigation scheduling, and irrigation water requirement (IR), using rainfall, soil, crop, and climate data [12].

The program includes general data for various crop features, local climate, and soil properties and helps improve irrigation schedules and the computation of scheme water supply for different crop patterns under irrigated and rainfed conditions [12].

2.3. Data Requirement

Four types of data are required for using the CROPWAT software, namely, rainfall data, climatic data, soil data, and crop data [13].

Climatic data for thirty years (1970–2000) were gathered from the Nasiriyah Meteorological Station (Table 2), obtained from the CLIMWAT 2.0 which is a climatic database to be used in association with the CROPWAT program and which allows the calculation of IRs for different crops for a range of climatological stations around the world [12].

CLIMWAT contains seven long-term monthly climatic parameters with the coordinates and altitude of the location. These parameters are monthly maximum and minimum temperature (°C), wind speed (km/h), mean relative humidity (%), sunshine hours (h), rainfall data (mm), and effective rainfall (mm) [7].

The crop data for wheat, barley, white corn, and 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 [7]. Planting dates were taken according to the guide to agricultural operations in Iraq of the Department of Extension and Agricultural Training [11].

The soil parameters obtained from the FAO CROPWAT 8.0 model include detailed information on the soil near the climatic station, such as total available moisture content, initial moisture depletion, maximum rain infiltration rate, and maximum rooting depth. The United States Department of Agriculture (USDA) soil conservation (S.C.) method was used in this study [12]. The soil in the Dhi-Qar area is considered as a medium type according to FAO standards [14].

2.4. Reference Evapotranspiration (ET_0)

Transpiration (water lost from the plant surface) and evaporation (water lost from the soil surface) occur at the same time and, when combined, are referred to as evapotranspiration (ET). The rate of ET from a hypothetical crop with a height of 0.12 m, albedo (0.23), and fixed canopy resistance (70 sm^{-1}) is called the reference evapotranspiration [15].

The Windows CROPWAT model uses the FAO Penman–Monteith equation for the calculation of the ET_0 where most of the parameters are measured from the weather data.

The Penman–Monteith equation form is as follows:

$$\lambda\, ET = \frac{\Delta(Rn - G) + Pa\, Cp\dfrac{(es - ea)}{ra}}{\Delta + \gamma\left(1 + \dfrac{rs}{ra}\right)} \tag{1}$$

where Rn is the net radiation, G is the soil heat flux, $(es - ea)$ is the vapor pressure deficit of the air, Pa is the mean of air density at constant pressure, Cp is the specific heat of the air, Δ is the slope of the relationship between saturation vapor pressure and air temperature, γ is psychometric constant, and rs and ra are the surface and aerodynamic resistances, respectively [16].

When the theoretical crop traits and the standard height for wind speed (2 m) are applied to calculate the "bulk" surface resistance and the aerodynamic resistance, Equation (1) can be derived as follows:

$$ET_0 = \frac{0.408\Delta(Rn - G) + \gamma\frac{900}{T+273}u2(es - ea)}{\Delta + \gamma(1 + 0.34\, u2)} \tag{2}$$

where ET_0 is the reference evapotranspiration (mm/day), T is the mean daily air temperature (°C) at 2 m height, $u2$ is the wind speed at 2 m height (ms^{-1}), and es and ea are the saturation and actual vapor pressure (kPa), respectively [12].

2.5. Crop Water Requirement (CWR)

The crop water requirement is the amount of water equal to what is lost from a cropped field by the *ET* and is expressed by the rate of *ET* in mm/day. Estimation of CWR is derived from crop evapotranspiration (*ETc*) which can be calculated by the following equation [17]:

$$ETc = Kc \times ET_0 \quad (3)$$

where *Kc* is the crop coefficient. It is the ratio of the crop *ETc* to the ET_0, and it represents an integration of the effects of four essential qualities that differentiate the crop from reference grass, and it covers albedo (reflectance) of the crop–soil surface, crop height, canopy resistance, and evaporation from the soil. Due to the *ET* differences during the growth stages, the *Kc* for the crop will vary over the developing period which can be divided into four distinct stages: initial, crop development, mid-season, and late season [15].

2.6. Irrigation Water Requirement (IR)

The CROPWAT Model can compute the daily water balance of the root zone as far as root zone depletion at the day's end by the following equation [18]:

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

where *Dr,i* is the root zone depletion at the day's end *i* (mm), *Dr,i*−1 is the water content in the root zone at the previous day's end (mm), *Pi* is the precipitation on day *i* (mm), *ROi* is the surface soil runoff on day *i* (mm), Ii is the net irrigation depth on day i which infiltrates the soil (mm), Cri is the capillary rise from the groundwater table on day *i* (mm), *ETci* is the crop evapotranspiration on day *i* (mm), and *DPi* is the lost water of the root zone on day *i* (mm).

2.7. Irrigation Schedule

Irrigation scheduling determines the correct measure of water to irrigate and the correct time for watering. The CROPWAT model calculates the ET_0, CWR, and IRs to develop the irrigation schedules under different administration conditions and water supply plans [19].

3. Results and Discussion

The data which were entered into the CROPWAT and CLIMWAT software included the country (Iraq), climatic station (Nasiriya), type of crop, date of cultivation, and soil type (clay, heavy). Once all the data were entered into the software, it calculated the climatic parameters, ET_0, effective rainfall, and total irrigation requirements for the studied crop.

Other outputs of the CROPWAT program are presented in tables and charts in the next paragraphs. Table 1 contains data about the four crops in this study. Table 2 contains the climate characteristics of the Nasiriya area.

Table 1. Data for the four crops in this study.

Crops	Scientific Name	Planting and Harvesting Date	Critical Depletion Fraction	Rooting Depths (cm)	Crop Growth Periods (Days)			
					Initial	Crop Develop.	Mid-Season	Late Season
Wheat	*Triticum aestivum*	15 November–24 March	0.55	120	30	30	40	30
Barley	*Hordeum vulgare*	15 November–24 March	0.55	110	15	25	50	30
White corn	*Sorghum bicolor*	25 March–12 July	0.60	140	20	35	45	30
Tomatoes	*Solanum lycopersicum*	15 March–6 August	0.30	100	30	40	45	30

Table 2. Climate characteristics, rainfalls, and ET_0 of Nasiriya area (average for 1970–2000 period) obtained using the CLIMWAT tool attached to the CROPWAT software.

Month	Temp. (°C)		Humidity (%)	Wind (km/day)	Sun (h)	Rad. (MJ/m^2/day)	ET_0 (mm/day)	Rain (mm)	Eff. Rain (mm)
	Min	Max							
January	5.9	17.8	63	207	5.5	10.7	2.19	24	23.1
February	7.7	20.4	60	225	6.8	14.2	2.89	16	15.6
March	11.5	24.9	46	268	7.4	17.6	4.66	15	14.6
April	16.6	30.7	42	277	7.8	20.3	6.24	18	17.5
May	22.4	36.9	39	285	9.1	23.4	8.08	9	8.9
June	25.3	40.2	33	337	9.5	24.3	9.92	0	0
July	26.1	42.8	32	328	10.2	25.1	10.5	0	0
August	25.2	43.6	28	294	9.8	23.5	10	0	0
September	22	41.3	28	242	9.2	20.6	8.21	0	0
October	17.1	35.4	39	225	8.5	16.9	5.99	4	4
November	12	26.1	52	225	7	12.7	3.74	8	7.9
December	6.8	18.9	61	199	5.9	10.5	2.29	13	12.7
Total								107	104.3
Average	16.6	31.6	44	259	8.1	18.3	6.23		

3.1. Reference Evapotranspiration and Effective Rainfall Estimation

The ET_0 was estimated from alfalfa, the reference standard crop which has an actively growing, uniform surface of grass shading the ground completely. The ET of the crop under consideration (*ETc*) can be obtained by adjusting ET_0 using crop coefficient (*Kc*) as in Equation (5) as follows [20]:

$$ET_0 = ETc/Kc \quad (5)$$

The ET_0 values obtained from the CROPWAT software for different months are as shown in Table 2.

It is high in summer due to the high temperature and the highest value was in July (10.5 mm). It decreases in winter and the lowest value was in January (2.19 mm) due to the low temperature. The annual mean was 6.23 mm.

The differences in ET_0 values reflect the variation in weather parameters in the study area. The low relative humidity, high temperatures, and high wind increased the evapotranspiration during the dry seasons [21].

Tables 3–6 show the *ETc* increasing through the growth stages and decreasing slightly at the later stages. The variations observed here can be due to the crop coefficient as shown in Equation (3). Although the *Kc* varied little, it was not constant in any growth stage; this also expresses the seasonal crop water needs [22].

The *ETc* values were observed to be low at the start and end when the crops were at their productive stage and greater in the mid stages of all the four crops.

Effective rainfall is the part of rainfall which is effectively used by the crop after losses by surface runoff and deep filtration; it is used to evaluate the CWR. The main features of rainfall are its amount, frequency, and intensity which differ temporally and spatially. Exact knowledge of these three main features is essential for planning its full use [7].

The average annual rainfall of 30 years (1970–2000) and the CROPWAT rainfall from the USDA S.C. method are used here to estimate the effective rainfall and to calculate the water requirements and irrigation schedules for the four crops [12]. As shown in Table 2, the results indicate that the average annual rainfall value was 107 mm and about 104.3 mm was effective rainfall. Tables 3–6 show that 97.4%, 63.1%, 29.6%, and 34.3% of rainfall have been used effectively by wheat, barley, white corn, and tomatoes, respectively.

3.2. Crop Water Requirement of Wheat, Barley, White Corn, and Tomatoes

The crop water need is the amount (or depth) of water that equals the water loss by ET.

Crops have different water requirements depending upon the place, climate, soil type, cultivation method, effective rain, etc., and the total water required for crop growth is not equally distributed over its whole life span [22]. The irrigation water requirements (IRs) for the four crops included in this study are in the following order according to the (mm/dec) unit:

Tomatoes (1180) > Wheat (1142) > White corn (844.8) > Barley (203.2).

Tables 3–6 illustrate the effective rain and the IR of wheat, barley, white corn, and tomatoes calculated by CROPWAT.

Table 3. Crop water requirement for wheat. (Init, initial; Dev, development; Eff. Rain, effective rain; Irr. Req., irrigation requirements).

Month	Decade	Stage	*Kc* (Coeff.)	*ETc* (mm/day)	*ETc* (mm/dec)	Eff. Rain (mm/dec)	Irr. Req. (mm/dec)
November	2	Init	0.70	2.62	15.7	1.6	14.4
November	3	Init	0.70	2.28	22.8	3.2	19.6
December	1	Init	0.70	1.89	18.9	3.6	15.4
December	2	Dev	0.71	1.55	15.5	4.0	11.4
December	3	Dev	0.74	1.62	17.9	5.3	12.6
January	1	Dev	0.78	1.73	17.3	7.1	10.2
January	2	Dev	0.82	1.78	17.8	8.5	9.3
January	3	Dev	0.85	2.06	22.7	7.4	15.3
February	1	Dev	0.89	2.31	23.1	5.9	17.2
February	2	Dev	0.93	2.59	25.9	4.9	20.9
February	3	Dev	0.96	3.27	26.2	4.9	21.2
March	1	Dev	0.99	4.03	40.3	4.9	35.4
March	2	Dev	1.03	4.77	47.7	4.7	43.0
March	3	Dev	1.06	5.51	60.7	5.1	55.6
April	1	Dev	1.10	6.29	62.9	5.8	57.1
April	2	Dev	1.14	7.10	71.0	6.3	64.7
April	3	Dev	1.17	8.03	80.3	5.2	75.1
May	1	Mid	1.20	8.94	89.4	3.9	85.4
May	2	Mid	1.20	9.67	96.7	3.0	93.7
May	3	Mid	1.20	10.40	114.4	2.0	112.5
June	1	Mid	1.20	11.21	112.1	0.1	112.0
June	2	Late	1.08	10.85	108.5	0.0	108.5
June	3	Late	0.77	7.85	78.5	0.0	78.5
July	1	Late	0.46	4.72	47.2	0.0	47.2
July	2	Late	0.27	2.82	5.6	0.0	5.6
					1239.1	97.4	1142.0

Table 4. Crop water requirement for barley.

Month	Decade	Stage	*Kc* (Coeff.)	*ETc* (mm/day)	*ETc* (mm/dec)	Eff. Rain (mm/dec)	Irr. Req. (mm/dec)
November	2	Init	0.30	1.12	6.7	1.6	5.4
November	3	Dev	0.30	0.99	9.9	3.2	6.7
December	1	Dev	0.52	1.42	14.2	3.6	10.6
December	2	Dev	0.87	1.90	19.0	4.0	15.0
December	3	Mid	1.14	2.50	27.5	5.3	22.3
January	1	Mid	1.16	2.58	25.8	7.1	18.7
January	2	Mid	1.16	2.54	25.4	8.5	16.9
January	3	Mid	1.16	2.81	30.9	7.4	23.6
February	1	Mid	1.16	3.01	30.1	5.9	24.2
February	2	Late	1.05	2.94	29.4	4.9	24.4
February	3	Late	0.78	2.67	21.4	4.9	16.4

Table 4. *Cont.*

Month	Decade	Stage	*Kc* (Coeff.)	*ETc* (mm/day)	*ETc* (mm/dec)	Eff. Rain (mm/dec)	Irr. Req. (mm/dec)
March	1	Late	0.51	2.07	20.7	4.9	15.8
March	2	Late	0.30	1.38	5.5	1.9	3.1
Total					266.5	63.1	203.2

Table 5. Crop water requirement for white corn.

Month	Decade	Stage	*Kc* (Coeff.)	*ETc* (mm/day)	*ETc* (mm/dec)	Eff. Rain (mm/dec)	Irr. Req. (mm/dec)
March	3	Init	0.30	1.56	10.9	3.2	8.4
April	1	Init	0.30	1.72	17.2	5.8	11.3
April	2	Dev	0.36	2.26	22.6	6.3	16.3
April	3	Dev	0.57	3.92	39.2	5.2	34.0
May	1	Dev	0.79	5.89	58.9	3.9	55.0
May	2	Mid	1.00	8.08	80.8	3.0	77.8
May	3	Mid	1.06	9.22	101.4	2.0	99.4
June	1	Mid	1.06	9.94	99.4	0.1	99.2
June	2	Mid	1.06	10.62	106.2	0.0	106.2
June	3	Late	1.05	10.71	107.1	0.0	107.1
July	1	Late	0.94	9.73	97.3	0.0	97.3
July	2	Late	0.79	8.40	84.0	0.0	84.0
July	3	Late	0.67	6.96	48.7	0.0	48.7
					873.7	29.6	844.8

Table 6. Crop water requirement for tomatoes.

Month	Decade	Stage	*Kc* (Coeff.)	*ETc* (mm/day)	*ETc* (mm/dec)	Eff. Rain (mm/dec)	Irr. Req. (mm/dec)
March	2	Init	0.60	2.79	16.8	2.8	14.4
March	3	Init	0.60	3.11	34.2	5.1	29.1
April	1	Init	0.60	3.43	34.3	5.8	28.4
April	2	Dev	0.64	4.01	40.1	6.3	33.7
April	3	Dev	0.79	5.40	54.0	5.2	48.8
May	1	Dev	0.94	7.00	70.0	3.9	66.1
May	2	Dev	1.09	8.79	87.9	3.0	84.9
May	3	Mid	1.20	10.39	114.3	2.0	112.4
June	1	Mid	1.20	11.24	112.4	0.1	112.3
June	2	Mid	1.20	12.02	120.2	0.0	120.2
June	3	Mid	1.20	12.21	122.1	0.0	122.1
July	1	Late	1.19	12.37	123.7	0.0	123.7
July	2	Late	1.10	11.69	116.9	0.0	116.9
July	3	Late	0.98	10.22	112.4	0.0	112.4
Aug	1	Late	0.89	9.07	54.4	0.0	54.4
Total					1213.8	34.3	1180

3.3. Net Irrigation Requirement (NIR) and Irrigation Schedule

Knowledge of crop irrigation water requirements and irrigation time schedules improves irrigation management in the field. Irrigation water management is about controlling the amount, timing, and rate of irrigation in an efficient and planned manner. Tables 7–10 and Figures 2–5 illustrate the field crop irrigation schedules for the wheat, barley, white corn, and tomato crops.

The total gross irrigation mean and the total net irrigation mean are 343.8 mm and 240.7 for wheat, 175.2 mm and 122.6 mm for barley, 343.8 mm and 240.7 mm for white corn, and 203.3 mm and 142.3

mm for tomatoes. There are five irrigation schedules for wheat, three for barley, four for white corn, and twelve for tomatoes.

The NIR is the water quantity required for the growth of the crop, or it is the amount of water necessary to reach the field capacity of the soil. NIR depends on the climate and cropping pattern. Data on irrigation efficiency are needed to convert NIR to gross irrigation requirement. The different losses, such as runoff, seepage, evaporation, and percolation, take place during application and transport of irrigation water [13]. Operations, such as leaching, transplantation, and land preparation, require certain amounts of water. Thus, CWR includes ET, losses during the application of water needed for these purposes as in Equation (6).

$$NIR = ETc - Eff.rain \tag{6}$$

This kind of analysis helps farmers to choose the type of crops for cultivation based on the availability of water.

Table 7. Irrigation schedules for wheat.

Date	Day	Stage	Rain (mm)	Ks (fract.)	Eta (%)	Depl. (%)	Net Irr. (Mm)	Deficit (mm)	Loss (mm)	Gr. Irr. (mm)	Flow (L/s/ha)
1 March	107	Dev	0.0	1.00	100	56	170.1	0.0	0.0	243.0	0.26
16 April	153	Dev	0.0	1.00	100	56	225.8	0.0	0.0	322.6	0.81
16 May	183	Mid	0.0	1.00	100	56	245.3	0.0	0.0	350.4	1.35
8 June	206	Mid	0.0	1.00	100	55	240.7	0.0	0.0	343.8	1.73
12 July	End	End	0.0	1.00	0	60					

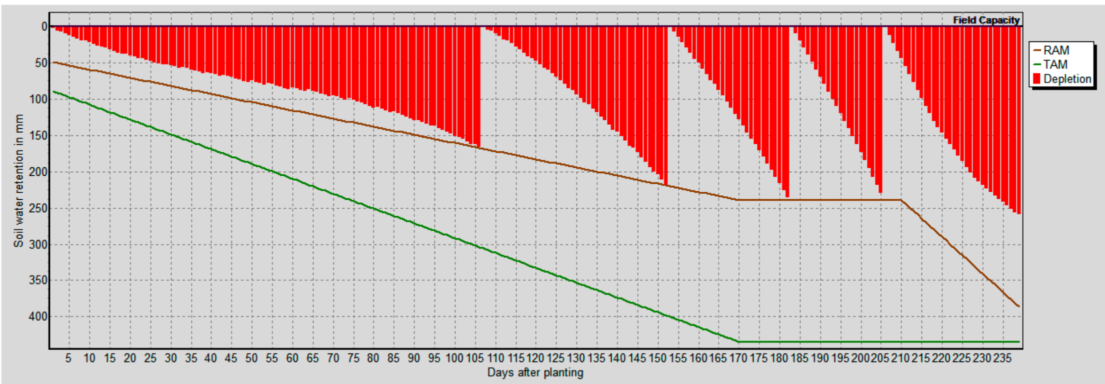

Figure 2. Irrigation schedules for wheat.

Table 8. Irrigation schedules for barley.

Date	Day	Stage	Rain (mm)	Ks (fract.)	Eta (%)	Depl. (%)	Net Irr. (mm)	Deficit (mm)	Loss (mm)	Gr. Irr. (mm)	Flow (L/s/ha)
19 November	5	Init	0.0	1.00	100	56	44.5	0.0	0.0	63.6	1.47
30 December	46	Mid	0.0	1.00	100	56	122.6	0.0	0.0	175.2	0.49
14 March	End	End	0.0	1.00	0	65					

Table 9. Irrigation schedules for white corn.

Date	Day	Stage	Rain (mm)	Ks (fract.)	Eta (%)	Depl. (%)	Net Irr. (mm)	Deficit (mm)	Loss (mm)	Gr. Irr. (mm)	Flow (L/s/ha)
21 May	58	Mid	0.0	1.00	100	52	211.3	0.0	0.0	301.8	0.60
12 June	80	Mid	0.0	1.00	100	52	210.6	0.0	0.0	300.9	1.58
5 July	103	End	0.0	1.00	100	59	240.7	0.0	0.0	343.8	1.73
27 July	End	End	0.0	1.00	0	43					

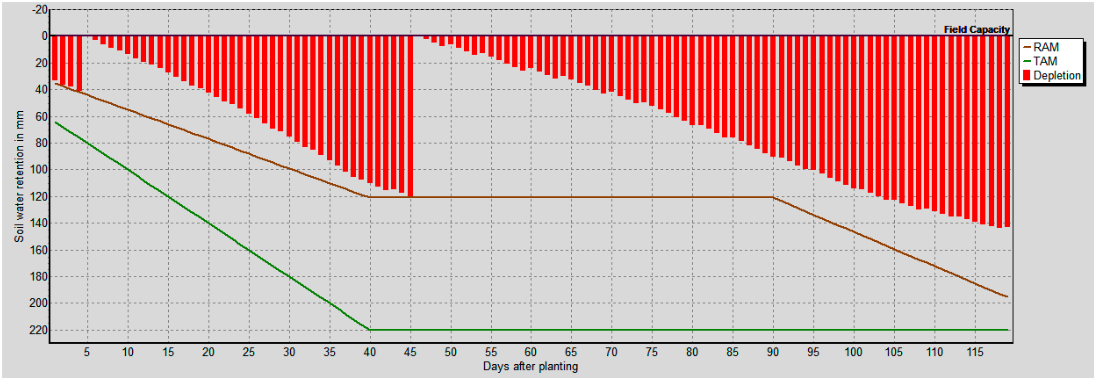

Figure 3. Irrigation schedules for barley.

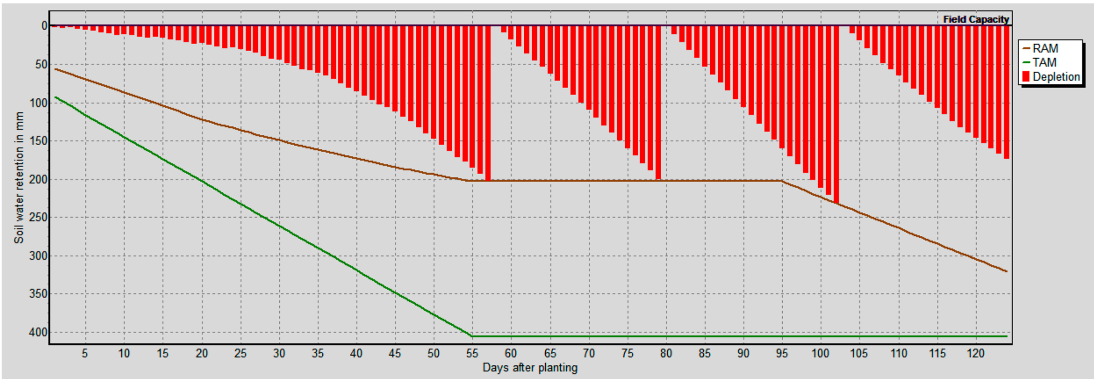

Figure 4. Irrigation schedules for white corn.

Table 10. Irrigation schedules for tomatoes.

Date	Day	Stage	Rain (mm)	Ks (fract.)	Eta (%)	Depl. (%)	Net Irr. (mm)	Deficit (mm)	Loss (mm)	Gr. Irr. (mm)	Flow (L/s/ha)
29 March	15	Init	0.0	1.00	100	31	37.1	0.0	0.0	53.1	0.41
16 April	33	Dev	0.0	1.00	100	32	55.4	0.0	0.0	79.1	0.51
2 May	49	Dev	0.0	1.00	100	35	78.7	0.0	0.0	112.5	0.81
16 May	63	Dev	0.0	1.00	100	39	105.2	0.0	0.0	150.3	1.24
28 May	75	Mid	0.0	1.00	100	40	116.2	0.0	0.0	166.0	1.60
8 June	86	Mid	0.0	1.00	100	42	120.9	0.0	0.0	172.7	1.82
18 June	96	Mid	0.0	1.00	100	41	118.5	0.0	0.0	169.3	1.96
28 June	106	Mid	0.0	1.00	100	42	121.7	0.0	0.0	173.8	2.01
8 July	116	End	0.0	1.00	100	43	123.4	0.0	0.0	176.3	2.04
19 July	127	End	0.0	1.00	100	45	130.0	0.0	0.0	185.7	1.95
2 Aug	141	End	0.0	1.00	100	49	142.3	0.0	0.0	203.3	1.68
6 Aug	End	End	0.0	1.00	0	9					

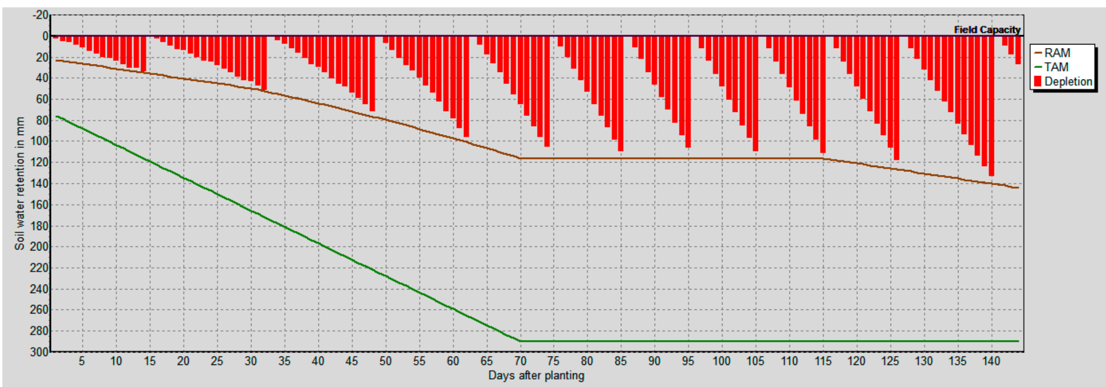

Figure 5. Irrigation schedules for tomatoes.

In the above figures, (TAM) is the total available moisture or the total amount of water available to the crop. The (RAM) is the readily available water or the portion of (TAM) that the plant can get from the root zone without facing water stress [23].

Agriculture in Iraq is a vital component of the country's economy. It was the primary economic activity in Iraq before the development of the petroleum industry. There is now a strong debate about which direction Iraqi agriculture should take, for its revival and for contribution to the nation, taking into account the growing national and regional competition over scarce water resources and the challenges of climate change [24].

Irrigation has probably been practiced in Iraq for over 10,000 years. The phenomena of soil waterlogging and salinity have evolved over this long irrigation period. It is estimated by the FAO that 75% of Iraq's irrigated area is at least moderately saline, with as much as 20 to 30% of the land suitable for irrigation not farmed due to salinity [25].

Water losses throughout Dhi-Qar Province are substantial in irrigation schemes. Water is generally transported to the farmers' fields through very poorly maintained distribution systems made of earth canals and ditches that suffer substantial water loss due to infiltration, flow, or leakage. [3].

Irrigation is used for rice, maize, dates, vegetables, and fruits in the summer in southern Iraq including Dhi-Qar Province. The main irrigated winter crops are wheat and barley, with production ranging from one-third (33%) to one-half (50%) of total agricultural production in Iraq [24].

Table 11 shows the quantities produced and the cultivated areas of the four crops covered by this study in the province of Dhi-Qar compared to all of Iraq.

It is clear that the production of these four crops in the province constitutes a small proportion of the country's production and, therefore, there is an urgent need to reform farming and irrigation systems for the purpose of increasing production. Irrigation system reform follows modern methods such as sprinkling and drip irrigation with emphasis on important crops, water availability and soil quality. An important factor is to raise awareness among farmers about the need to save water and use modern methods.

Table 11. The quantities produced and cultivated areas of the four crops covered by this study.

	Wheat		Barley		White Corn		Tomatoes	
	dunam	**ton**	**dunam**	**ton**	**dunam**	**Ton**	**dunam**	**ton**
Dhi-Qar Province	208,967	123,701	108,623	37,052	6736	1714	1803	3929
All of Iraq	4,215,906	2,974,136	820,461	303,114	11,064	2943	55,523	123,611

4. Conclusions

Using the FAO CROPWAT 8.0 model yielded an interesting result. It can readily be seen that crop water requirements and schedules were specific to the local study area owing to the seasonal and ecological features of the province. The summer crop (tomato) had higher amounts of evapotranspiration and water requirements and more frequent irrigation schedules than the other three crops following this order:

$$\text{Tomato} > \text{wheat} > \text{white corn} > \text{barley}.$$

The study results enhance our understanding of the water requirements of some major crops in Iraq, which will consequently help improve the management of water resources and the productivity through policies based on these findings.

The use of scientific tools like CROPWAT and CLIMWAT can assess the CWRs with a high degree of accuracy and suggest the crop pattern and crop rotation that farmers can readily accept.

The results of this study can be used by water resource planners for future planning, thereby helping to save water in meeting the CWRs, and can be used as a guide for farmers to select the amount and frequency of irrigation for the crops being studied.

A comprehensive plan should be prepared to estimate the CWRs for all zones in Iraq which lack such studies. It is possible to use such a plan as a basis for agricultural projects. However, practical tests must confirm the use of these software tools.

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