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ARTICLE

Estimating Crop and Reference Evapotranspiration and Crop Factor and Some Growth Indicators for Wheat and Barley in Dhi Qar Governorate Using the CropWat Program

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ABSTRACT

Information about the average water consumption or evapotranspiration of crops is the basis for scheduling irrigation and the water requirements of plants, and choosing the appropriate crops for the region in light. This experiment was carried out to evaluate and calculate the ability of the CropWat program to estimate evapotranspiration rates, and plant consumptive water use for strategic crops in Iraq, including wheat and barley in Dhi Qar Governorate. The results of the study showed that the maximum root depth ranged between 1.20 m, and 1.10 m in the distance between the vegetative growth and flowering stages for wheat and barley crops, respectively. It was also noted that the crop evapotranspiration (ETc) values decreased at the beginning of the growing season, ranging from 0.79 mm day^{-1} to 1.57 mm day^{-1} for wheat and barley crops, respectively. Then, the values increased with the progress of the growing season and the increase of the vegetative mass of the plants, reaching 3.72 mm day^{-1} and 3.46 mm day^{-1} for wheat and barley crops, respectively. The reference evapotranspiration (ETo) values were also low in the first months of the year and were around 2.1 mm day^{-1} at the beginning, then gradually increased with the progress of the months of the year, reaching the maximum reference evapotranspiration values of 10.5 mm day^{-1} in the seventh month, and then the values decreased at the end of the season for wheat and barley crops.

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Keywords: Evapotranspiration; Irrigation Scheduling; Water Consumption; Crop Factor

1. Introduction

The arid regions and semi-arid regions of the world are suffering from an increasing lack of available water resources, as the lack of rainfall affects soil productivity. Water in Iraq is of particular importance due to its scarcity, limited availability, and irregular distribution in time and space. With the increasing scarcity and need for water, it is necessary to evaluate water resources in quantity and quality in terms of their importance to agricultural production. Therefore, there is utmost importance in estimating soil moisture and water losses by evaporation in all its forms, whether reference or crop [1]. The urgent need to increase water use efficiency stems from the scarcity of water resources and the increasing demand for water on the one hand, and from the need to address the food crisis in developing countries on the other hand. Therefore, improving water use efficiency is the key to sustaining agricultural production in conditions of limited water resources [2]. Decision makers and water resource managers seek to explore and develop alternatives for cropping systems (composition, area distribution), irrigation schedules, irrigation systems used and fertilization; in order to improve WUE while achieving the objectives related to the quantity and quality of production.

Consumptive water use is defined as the required amount of water consumed by the plant system, including the amount of water used by transpiration through the plant leaves, the amount of water lost by evaporation from the soil surface, and the amount of water used in building the plant tissues themselves. Thus, we can say that water consumption (Cu) is equal to what is called evapotranspiration (ET). It is necessary in water balance calculations and has received the attention of irrigation and crop specialists in order to reach, in their calculations, the development plans and water quotas for irrigation and yield projects. It is also expressed, as the total amount of water needed for ET from the beginning of cultivation to harvest, given to a specific crop under specific climatic conditions, so that a sufficient amount of soil moisture is maintained through rain or irrigation at a level that does not affect growth and productivity [3]. Evaporation is criterion and element in the surface water balance and the hydrological cycle in most regions, including dry countries. Evaporation is usually associated with daily variations in climatic conditions. The water requirements for the crop are affected by climate conditions, the type and nature of the crop, the physical and hydrological characteristics of the soil, water retention, as well as the role of fertilizers, fertility, and other practices. Among these different inputs, the amount of water and the timing of addition are of great importance, in addition to the importance of not causing significant water stress on the plant or adding excessive amounts during irrigation. Calculating and knowing water requirements is important in most productive agricultural projects, and therefore it is necessary to estimate the interactions and influences between soil, water, and the climatic conditions of the region [4].

Evapotranspiration is the total evaporation from plants and from the soil, depending on factors related to the components of agriculture, including soil, plants, and atmosphere. The process of measuring evapotranspiration (ET) is complex and requires expensive tools in contrast to measuring rainfall, so it can be estimated using hydrological models [5]. The process of estimating evaporation is based on the amounts of effective or total precipitation within a specific period [6]. Irrigation management and scheduling depend on the method by which the time and depth of irrigation are determined in advance based on information about climatic factors and the conditions of the region. This method aims to fill the deficit in soil moisture resulting from water consumption or evapotranspiration, or in other words, to ensure that the plant obtains its water requirements at the appropriate time [7]. The importance of water and irrigation in agriculture appears when water supply is scarce and expensive, or when climatic, natural or soil conditions restrict water movement and root growth [8]. Therefore, irrigation management and scheduling have become essential tools for improving water use efficiency and increasing production. This will lead to increased returns and maximizing the availability of water resources in addition to reducing deep penetration losses, evaporation, water losses, soil flooding and thus drainage requirements [9]. Water is the main criterion for evaluating the productivity of agricultural production systems in areas characterized by limited water resources. The amount of irrigation water added and the time required for irrigation are determined by the prevailing climate conditions, the cultivated crop, its growth stage, the soil water storage capacity, and the growth of the extended root in the soil, which is also determined by the type of crop, its growth stage, and the soil [10]. The climate of Dhi Qar city is considered to be within the semi-arid tropical climate, and calcareous soils are widespread in the dry and semi-arid regions of the world. These soils are impermeable, and the availability of water is low. Climate is one of the most important factors affecting the growth and productivity of agricultural crops, and climate factors can be used to estimate the water requirements of crops. The water requirements of a crop are the total amounts of water that must be given to a specific crop in a specific climate from the beginning of planting to harvest, so that a sufficient amount of soil moisture is maintained at an appropriate level that does not affect the growth of the plant and the amount of the crop.

Crop factor reflects the crop's water requirement, so high values of the coefficient indicate a high water requirement. It combines the influence of different weather conditions on the reference evaporation, the type and nature of plants, and the natural effects of water lost through evaporation from the soil surface. Thus, the crop factor is a coefficient that determines whether the actual evapotranspiration value is similar to or greater than the reference evapotranspiration value estimated through climate data [11, 12]. This study was applied to estimate effective rainfall and ET in Dhi Qar Governorate using the CropWat model; this program is one of the programs that has been updated by the FAO Land and Water Development Division to control the management of irrigation operations. It is also one of the common applications for meteorologists, agriculturalists, and irrigation engineers; to estimate evapotranspiration as a necessary source of water and crop irrigation [13]. This program is also one of the effective tools for improving the irrigation process and its schedule when we face a water shortage or deficit [14]. The research aims to use the CropWat program to study and calculate the factors affecting the water balance, including ET_C, ET_O, Kc, and some growth indicators for wheat and barley crops in Dhi Qar Governorate using the CropWat program.

2. Materials and Methods

2.1. CropWat Program

CropWat is a program This software, approved by FAO and the University of Southampton in its current version CROPWAT 8.0, is a powerful simulation software for simulating IWR using soil data, climate and crop data. The program also allows for scheduling crop irrigation at any water supply condition according to the amounts of water required for different crop types. This program is also considered an important applied method for estimating water budgeting and scheduling and the factors affecting them, including climatic and agricultural conditions [15]. The CropWat program is a mathematical program for irrigation management. Using this program and its daily water balance algorithm, it is possible to predict the possible outcomes of some hypothetical irrigation scenarios and estimate the expected decrease in productivity. The basic functions calculate the reference evapotranspiration (ETo) according to the Penman-Monteith equation, the crop water requirements and irrigation rates to develop irrigation schedules under different management conditions. It allows making recommendations to improve irrigation methods, planning irrigation schedules and evaluating production under rainy or deficit irrigation conditions [16]. The program can predict the effect of water stress on the crop using the productivity response factor. The CropWat program has been successfully used to estimate the water requirements of several crops (rice, maize, sorghum, soybeans) in different cropping patterns [17]. Many researchers in many countries have designed computer programs similar to the CropWat program based on the approach described in the Organization's publication 56, as these models generally agree that they can be used to improve the distribution of irrigation water between different crops or the distribution of water during the crop season [18]. In a study simulating the CropWat model under irrigated crop cultivation conditions in order to provide the necessary information for decision-making and support in irrigation management, the model effectively estimates the reduction in productivity resulting from water stress and climatic effects, making this model one of the best mathematical models in irrigation management and planning [19].

Also, the program is described as an effective tool for irrigation management as it effectively simulates the effect of water stress on production and the model simulates the general trend of soil water content changes in different irrigation treatments applied to the crop well [20, 21]. The study aims to estimate the effectiveness of rainfall and evapotranspiration in Dhi Qar Governorate through hydrological modeling using the FAO CropWat model. It works mainly on climate, soil data, and crop data . The program was applied to climate data representing some of the climate elements required by the program for Dhi Qar Governorate in Iraq to estimate crop evapotranspiration (ET_C), reference evapotranspiration (ET_O), and crop factor (Kc) on wheat and barley crops and on clay-textured soils. The program facilitates the calculation and estimation of the reference evapotranspiration value based on the basic climatic functions in the program. It is also possible to develop an irrigation scheduling plan under varying administrative conditions, calculate an irrigation water supply program for agricultural crop models, and estimate water needs using the daily water balance algorithm [9]. The program calculates and estimates the reference value of evaporation and transpiration (ET_O) using the Penman-Monteith equation, as shown below. It allows making recommendations to improve water resources management methods, scheduling irrigation dates, and evaluating production under rainy conditions or deficient irrigation [22].

$$ET0 = \frac{0.408\Delta(Rn - G) + \gamma \frac{Cste}{T_\alpha + 273} u_2 \left(e_s - e_a\right)}{\Delta + \gamma\left(1 + 0.34 u_2\right)} \quad (1)$$

Where:

ETo: Evapotranspiration, [mm day^{-1}]
R_n: Net Rad. [MJ m^{-2} day^{-1}]
G: Soil H. flu. [MJ m^{-2} $jour^{-1}$]
e_s: Saturation vapor pressure [kPa]
e_a: Actual vapor pressure [kPa]
Δ: Slope of saturation vapor pressure curve [kPa °C^{-1}]
γ: Psychometric constant [kPa °C^{-1}]
u_2: wind sp. at 2 m [m s^{-1}]

The Penman-Monteith method is considered the best method for estimating the water requirements of crops. The group of experts, consultants and researchers at the FAO, in cooperation with the World Commission on Irrigation and Drainage and the Climate Information Organization, recommended in May 1990 the use of the Penman-Monteith equation as a standard method for calculating water requirements from climate data and neglecting other equations [23]. The traditional method is also used for large areas, and the water consumption (Cu) for a specific area is calculated according to the following equation:

$$\text{Cu} = (\text{I} + \text{P}) + (\text{Gs} - \text{Ge}) - \text{R} \quad (2)$$

Where:

Cu = water consumption for a given area
I = amount of water entering that area in a year.
P = amount of precipitation in a year
Gs = amount of water stored in the soil at the beginning of the year.
Gr = amount of water stored in the soil at the end of the year.
R = amount of water exiting in a year.

The CropWat program contains standard values for basic indicators for a group of crops, and the values of these indicators can be adjusted when local measurements are available [23]. In this study, the values of the crop factor (Kc) were calculated from the following relationship:

$$ET_C = Kc * ET_O \quad (3)$$

Where: ETc is the seasonal water consumption of the crop (mm), Kc is the crop factor, and ETo is the reference evapotranspiration calculated using the Penman-Monteith equation (mm). This program depends on the input data, which is called inputs, that simulate the environmental and agricultural reality. Among these inputs are the following data: climate data, rain, crop, agricultural pattern, and soil. The climatic data includes the following data: Max. and Min. temp., humidity, wind speed, solar rad., and sum. rainfall. Using the program, as a first step, the study area was determined in Dhi Qar Governorate - Nasiriyah and its affiliated stations and geographical location coordinates, as in **Figure 1** as follows.

The stations of the study area in Dhi Qar Governorate - Nasiriyah and the geographical location coordinates are selected and determined according to the program data and as mentioned and programmed by the FAO organization. As for Iraq there are several stations, their number is 19 stations, as shown in **Table 1**. Accordingly, the required area and its coordinates are selected in a required and appropriate manner.

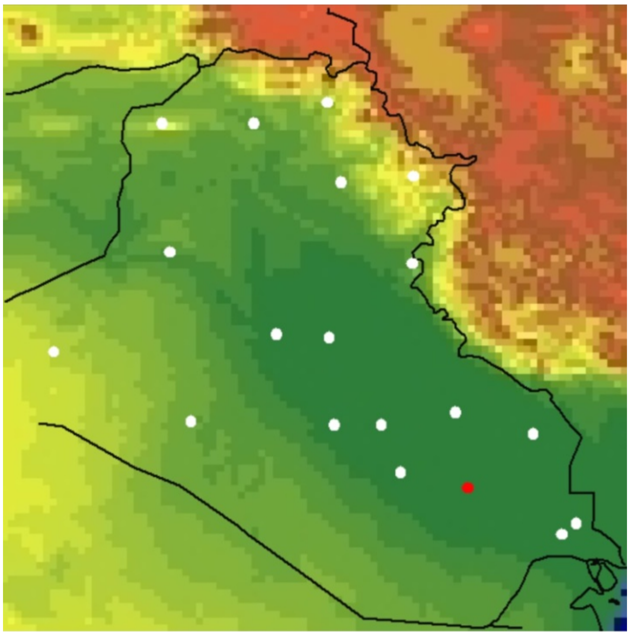


Figure 1. Map and location of the study, its stations and geographical location coordinates.

2.2. Input Data

- **Inputs for climate and evaporation elements (Climate/ET_O)**

The climatic elements and required data include the max Temp. and min Temp., humidity, wind, sun and radiation for the study site and throughout the months of the year. The data were as in **Table 2**.

- **Rain data inputs**

The rain data includes the monthly and total rainfall percentage and actual rain. This is done by specifying the study area, selecting the station, and entering the rain data in the rain data window using the program and according to the software data available to the FAO. The data was as throughout the months of the year in **Table 3** below.

- **Crop data inputs, planting method and growth stages**

Includes data for the crop to be studied or planted in terms of planting date, harvest, different growth stages throughout the season, root zone depth, crop response and critical penetration rate, as wheat and barley crops were selected and studied in this research.

The planting date in the program was adjusted to match the actual planting date implemented in the experiments, and the harvest date was left to be calculated by the program on the basis of the length of the phonological periods imposed by FAO publication 56. The effective root depth for the imposed data was also chosen according to the effective root depth previously calculated for the research experiments, as this value is included in calculating the amount of irrigation water and net water consumption. The month of the season was divided into three stages or periods, each of which is approximately 10 days. Crop coefficient and length of phonological periods The program requires crop coefficient values for three basic growth stages: the initial stage, the mid-season stage, and the harvest stage. As for the crop coefficient values in the development stage and the final stage of the crop, they are calculated implicitly with those stages according to FAO publication 56[22], noting that the Kc values during the development stage (stage two) and the maturity and harvest stage (stage four) were considered fixed values, as is the case with Kc values during the germination stage (stage one) and fruiting stage (stage three) according to FAO publication.

- **Soil data inputs**

Soil data inputs nclude data on the type or texture of the soil and some other characteristics, including the total moisture available in the soil, initial moisture, moisture penetration, and maximum infiltration rate. The program allows us to choose the texture class (soil name) as a main group from the following three main classes for light (sand), medium (loam) or heavy (clay) soils. To match this, the texture was also estimated in the laboratory using the hydrometer method. Some physical properties of the soil were measured, including the bulk density of the soil, the particle density of the soil, the total soil porosity, the degree of interaction or soil pH, and the soil salinity. The initial results were as follows, as in **Table 4**.

Also shows **Table 5** some general information about the soil of the region according to the type of soil and soil texture, and it contains the following data: total available soil moisture, maximum rain infiltration rate, maximum rooting depth, initial soil moisture depletion percentage, and initial available soil moisture.

Table 1. Stations affiliated with the study country and governorates in Iraq and their geographical location coordinates.

No.	Lon [*]	Lat [*]	Alt [m]	Name	Country
1	47.78	30.56	2	BASRAH	IRAQ
2	47.58	30.41	2	SHAIBAH	IRAQ
3	44.98	31.98	20	DIWANIYA	IRAQ
4	44.31	31.98	32	NAJAF	IRAQ
5	45.26	31.30	6	SEMAWA	IRAQ
6	46.23	31.08	3	NASSIRIYA	IRAQ
7	47.16	31.85	9	AMARAH	IRAQ
8	42.25	32.03	305	NUKAIB	IRAQ
9	46.05	32.16	15	KUT-AL-HAI	IRAQ
10	40.28	33.03	615	RUTVAH	IRAQ
11	43.48	33.28	45	HABBANIYAH-LAKE	IRAQ
12	44.23	33.23	34	BAGHDAD	IRAQ
13	41.95	34.46	150	ANA	IRAQ
14	45.43	34.30	202	KANAQIN	IRAQ
15	44.40	35.46	331	KIRKUK	IRAQ
16	45.45	35.55	853	SULAIMANIYA	IRAQ
17	41.83	36.31	476	SINJAR	IRAQ
18	43.15	36.31	223	MOSUL	IRAQ
19	44.21	36.61	1088	SALAHADDIN	IRAQ

Table 2. Climate and evapotranspiration inputs (Climate/ET_O) for the study location.

Country: Iraq, Location 6				Station: NASIRIYA			
Altitude: 3 m			Latitude: 31.08° N		Longitude: 46.23° E		
Month	**Min Temp.**	**Max Temp.**	**Humidity**	**Wind**	**Sun**	**Rad.**	**ET_O**
	°C	**°C**	**%**	**km day^{-1}**	**hours**	**MJ m^{-2} day^{-1}**	**mm day^{-1}**
January	5.9	17.8	63	207	6.7	12.0	2.23
February	7.7	20.4	60	225	7.5	15.0	2.93
March	11.5	24.9	46	268	8.4	18.9	4.76
April	16.6	30.7	42	277	9.6	22.9	6.50
May	22.4	36.9	39	285	10.5	25.5	8.34
June	25.3	40.2	33	337	11.3	26.9	10.24
July	26.1	42.8	32	328	12.4	28.4	10.92
August	25.2	43.6	28	294	12.9	28.0	10.53
September	22.0	41.3	28	242	12.5	25.2	8.65
October	17.1	35.4	39	225	11.1	20.2	6.23
November	12.0	26.1	52	225	8.3	14.0	3.80
December	6.8	18.9	61	199	6.9	11.4	2.31
Average	16.6	31.6	44	259	9.9	20.7	6.45

Table 3. Rain data inputs for the study location.

Month	**Rain**	**Eff. Rain**
	mm	**mm**
January	24.0	23.1
February	16.0	15.6
March	15.0	14.6
April	18.0	17.5
May	9.0	8.9
June	0.0	0.0
July	0.0	0.0
August	0.0	0.0
September	0.0	0.0
October	4.0	4.0
November	8.0	7.9
December	13.0	12.7
Total	107.0	104.3

3. Results and Discussion

3.1. Planting Style and Physiological Growth Stages

The results of **Figure 2** show that the best planting date for wheat in the study area is mid-November and the harvest date is late March. The planting date in the program is adjusted to suit the actual planting date in the region and according to the climatic conditions and type, and the harvest date is left to be calculated by the program on the basis of the length of the periods imposed by the FAO. The results also show that the length of the wheat season is 130 days

Table 4. Some primary physical and chemical properties of soil.

Soil Depth (cm)		Soil Separators	
30–15	15–0		
48.3	49.6	$g\ kg^{-1}$	Sand
315.8	321.6		Silt
631.3	583.4		Clay
Clay	Clay		Soil Texture
1.233	1.248	Bulk density	$mg\ m^{-3}$
2.678	2.632	Practical density	mg^{-3}
52.8	53.7	Total porosity %	
7.5	7.6	pH	
13.12	14.17	ECe	$dS\ m^{-1}$

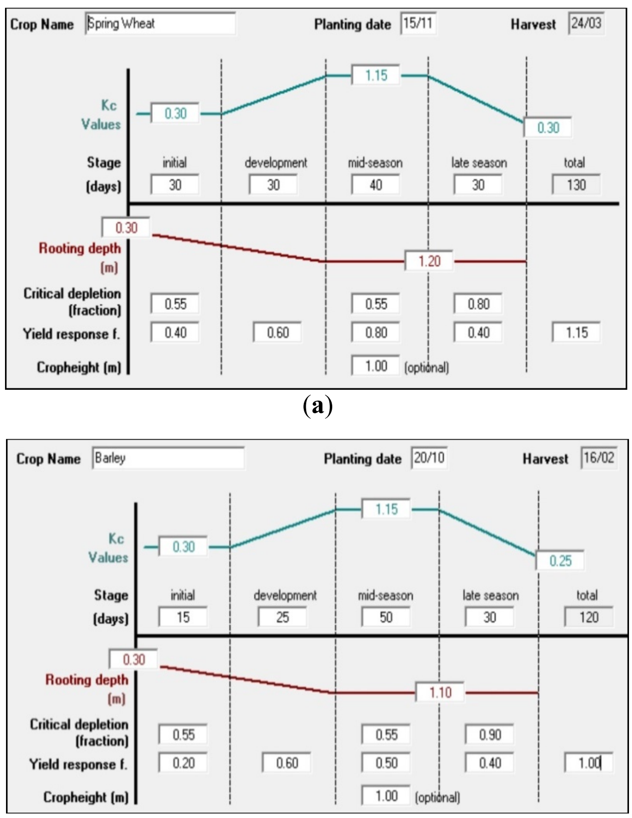
Table 5. General soil data for the study location.

General Soil Data	Soil Name: Heavy (Clay)	
	Value	Unit
Total available soil moisture (FC-WP)	200.0	mm meter^{-1}
Maximum rain infiltration rate	40	mm day^{-1}
Maximum rooting depth	900	cm
Initial soil moisture depletion (as % TAM)	0	%
Initial available soil moisture	200.0	Mm meter^{-1}

and is divided into the stages of early growth 30 days, then the development or vegetative growth stage 30 days, the flowering stage (mid-season) 40 days, and the maturity or end-of-season stage 30 days. While the best planting date for barley in the study area is after mid-October and the harvest date is mid-February. The results also show that the length of the barley season is 120 days and is divided into the stages of early growth 15 days, then the development or vegetative growth stage 25 days, the flowering stage (mid-season) 50 days, and the maturity or end-of-season stage 30 days.

Crop factor (Kc):

The results of **Figure 2** and the curve show that the crop factor increases with the initial growth period and rises upward at the vegetative growth stage, reaching the maximum crop factor at the flowering stage of about 1.15 in the middle of the season, and then decreases at the end of the season at maturity and harvest stage, and is 0.30. It is also noted that the crop factor curve for barley increases with the initial growth period and rises upward at the vegetative growth stage, reaching the maximum crop factor at the flowering stage of about 1.15 in the middle of the season, and then decreases at the end of the season at the maturity and harvest stage, and is 0.25. This is consistent with what was reached by[14, 23, 24].



(**a**)

(**b**)

Figure 2. Crop factor and growth indicators for (**a**) wheat and (**b**) barley crops and the farming pattern of the study location.

3.2. Crop Height and Rooting Depth

The plant height and effective root depth were selected for the imposed data according to the effective root depth previously calculated for the research experiments, as this value is included in the calculation of the amount of irrigation water and net water consumption. The results showed that the maximum rooting depth ranged between 1.20 m, and 1.10 m in the middle of the distance between the vegetative growth and flowering stages for wheat and barley crops, respectively. While the maximum height of wheat and barley crops ranged between 1.00 m in the middle of the distance between the vegetative growth and flowering stages.

3.3. Crop Evapotranspiration (ETc)

Table 6 data and results show that the evaporation values of the wheat crop were low in the early stages of growth and were around 0.79 mm day^{-1} in mid-January. The evapotranspiration values of the wheat crop increased with the progress of the growth period, and the maximum evapotranspiration of the crop occured at the end of February, and ranging around 3.72 mm day^{-1} then it decreased at the end of the growing season to around 1.78 mm day^{-1}. While the evapotranspiration values of the barley crop were low at the beginning of the season and were around 1.57 mm day^{-1} at the end of October. The evapotranspiration values of the barley crop increased with the progress of the growth period, and the maximum evapotranspiration of the crop occured at the end of November, ranging around 3.46 mm day^{-1} , and then decreased at the stage of maturity and harvest at the end of the season, with a value of 0.91 mm day^{-1}. The reason for the low values at the beginning of the season is due to the small vegetative mass of the crop, low transpiration, low temperatures, and consequently low evaporation. The reason for the high values as the growing season progresses is due to the large vegetative mass of the crop as well as high temperatures compared to the months preceding growth. This is consistent with Smith, Kivumbi and Heng[23] and Thanoun[24].

3.4. Reference Evapotranspiration (ETo)

The results in **Figure 3** show that the reference evapotranspiration values were low in the first months of the year, around 2.1 mm day^{-1} at the beginning, then gradually increased with the progress of the months of the year, reaching the maximum reference evapotranspiration values of 10.5 mm day^{-1} in the seventh month, and then the values progressively decreased at the end of the season for wheat and barley crops. The reason for this is the small green mass of the crop and the low transpiration, as well as the low temperatures and thus the low evaporation. While the reference evapotranspiration values increased with the progress of the period, the reason for this is the high temperatures compared to the months preceding growth and the low amount of rainfall during that period[25–27].

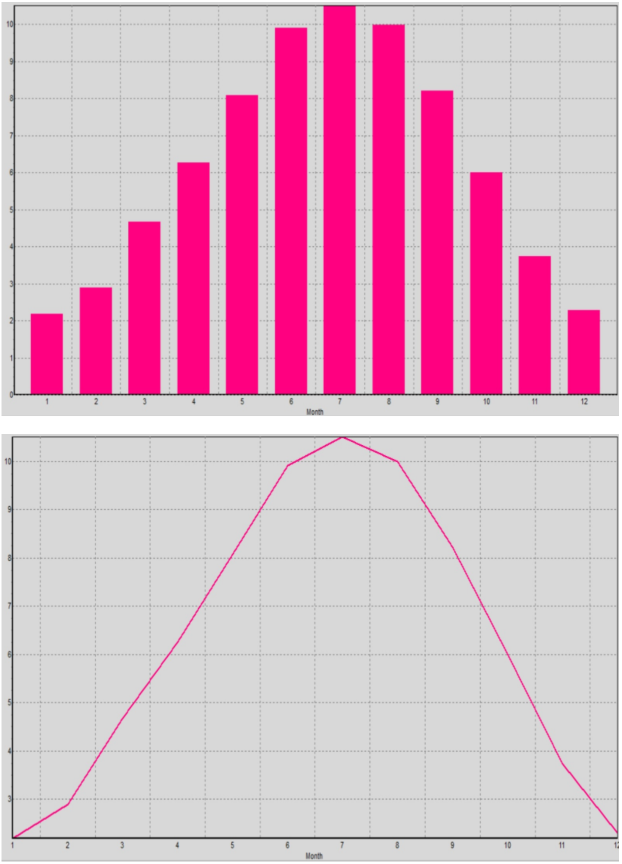


Figure 3. Reference evapotranspiration (ETo) values for the study location.

4. Conclusions

The crop evapotranspiration (ETc) values were low at the beginning of the growing season, ranging from 0.79 mm day^{-1} to 1.57 mm day^{-1} for wheat and barley crops, respectively. Then, the values increased with the progress of the growing season and the growth of the vegetative mass of the

Table 6. Crop evapotranspiration (ETc) data for (**a**) wheat and (**b**) barley crops at the study location.

(a)

Month	Decade	Stage	Kc Coeff	ETc mm/day
Nov	2	Init	0.30	1.12
Nov	3	Init	0.30	0.89
Dec	1	Init	0.30	0.81
Dec	2	Deve	0.36	0.79
Dec	3	Deve	0.65	1.41
Jan	1	Deve	0.95	2.11
Jan	2	Mid	1.16	2.53
Jan	3	Mid	1.17	2.82
Feb	1	Mid	1.17	3.02
Feb	2	Mid	1.17	3.26
Feb	3	Late	1.09	3.72
Mar	1	Late	0.83	3.39
Mar	2	Late	0.55	2.54
Mar	3	Late	0.34	1.78

(b)

Month	Decade	Stage	Kc Coeff	ETc mm/day
Oct	2	Init	0.30	1.80
Oct	3	Init	0.30	1.57
Nov	1	Deve	0.40	1.78
Nov	2	Deve	0.73	2.73
Nov	3	Mid	1.06	3.46
Dec	1	Mid	1.16	3.14
Dec	2	Mid	1.16	2.56
Dec	3	Mid	1.16	2.54
Jan	1	Mid	1.16	2.57
Jan	2	Late	1.14	2.49
Jan	3	Late	0.89	2.15
Feb	1	Late	0.57	1.47
Feb	2	Late	0.33	0.91

plants, reaching 3.72 mm day^{-1} and 3.46 mm day^{-1} for wheat and barley crops, respectively. The refErence evapotranspiration ETo was low in the first months of the year, around 2.1 mm day^{-1} at the beginning, then gradually increased with the progress of the months of the year, reaching the maximum reference evapotranspiration values of 10.5 mm day^{-1} in the seventh month, and then the values decreased at the end of the season for wheat and barley crops.

The values of the crop factor were similar for wheat and barley crops, as they increaseed during the initial growth period and rose progressively during the vegetative growth stage, reaching the maximum crop factor at the flowering stage of about 1.15 in the middle of the season, then decreased at the end of the season during the maturity and harvest stage. The importance of the CropWat program lies in its ability to determine and understand the role of total rainfall amounts and effective rainfall and their effect on the values of evapotranspiration, crop coefficient and growth indicators. It is recommended to apply the CropWat program in different areas of the country that differ in soil texture and climatic conditions to compare evapotranspiration rates, irrigation scheduling, and water requirements.

Author Contributions

Conceptualization, methodology, software, validation, formal analysis, investigation, resources, data curation, writing—original draft preparation, writing—review, editing, visualization and supervision Y.A.O.A.-S.; Conceptualization, methodology, software, validation, formal analysis, investigation, resources, data curation, writing—original draft preparation, writing—review, editing, visualization and supervision M.H.A.-B.

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The authors declare no conflict of interest.

References

[1] Wane, S.S., Nagdeve, M.B., 2014. Estimation of evapotranspiration and effective rainfall using CROPWAT. International Journal of Agricultural Engineering. 7(1), 23–26.

[2] Evett, S.R., Tolk, J.A., 2009. Introduction: Can water use efficiency be modeled well enough to impact crop management. Agronomy Journal. 101, 423–425.

[3] Hess, T.M., Molatakgosi, G., 2009. Irrigation management practices of cabbage farmers in Botswana using saline groundwater. Agricultural water management. 96(2), 226–232.

[4] Bos, M.G., Kselik, R.A.L., Allen, R.G., et al., 2009. Water requirements for irrigation and the environment. Wageningen Environmental Research: Wageningen, The Netherlands. pp. 1–300.

[5] Ács, F., Breuer, H., Szász, G., 2011. Estimation of actual evapotranspiration and soil water content in the growing season. Agrokémia és Talajtan. 56(2), 57–74.

[6] Patwardhan, A.S., Nieber, J.L., Johns, E.L., 1990. Effective rainfall estimation methods. Journal of irrigation and Drainage Engineering. 116(2), 182–193.

[7] Al-Haddad, A.H., Bakr, T.S., 2013. Irrigation scheduling effect on water requirements. Journal of Engineering. 19(01), 96–145.

[8] Jensen, M.E., Robb, D.C.N., Franzoy, C.E., 1970. Scheduling irrigations using climate-crop-soil data. Journal of Irrigation and Drainage of Division. 96(1), 25–38.

[9] Smith, M., 1992. CROPWAT—A computer program for irrigation planning and management. FAO Irrigation and Drainage Paper 46. FAO: Rome, Italy.

[10] Burman, R.D., Nixon, P.R., Wright, J.L., et al., 1981. Water requirements. In: Jensen, M.E. (Ed.). Design and operation of farm irrigation systems. ASAE Monograph: Lansing, MI, USA. Volume 3, pp. 189–232.

[11] Peacock, C.E., Hess, T.M., 2004. Estimating evapotranspiration from read bed using the brown ratio energy balance method. Hydrological Pocess. 18, 247–260.

[12] Kisekka, I., Migliaccio, K., Dukes, M.D., et al., 2010. Evapotranspiration-based irrigation for agriculture: Crop coefficients of some commercial crops in Florida. EDIS. 2, 8–16.

[13] FAO, 1992. CROPWAT, a computer program for irrigation planning and management by Smith M. FAO Irrigation and Drainage Paper No. 26. FAO: Rome, Italy.

[14] Rahimi, D., Salahshour, F., 2014. Estimation of water requirement, evaporation and potential transpiration of Brassica napus L plant in Ahwaz town Using CROWPWAT model. International Journal of Advanced Biological and Biomedical Research. 2(4), 1377–1387.

[15] Badr, H., Jalil, H., Khalil, T.A., 2014. Designing a program to calculate water needs in irrigation projects. Tikrit Journal of Engineering Sciences. 17(1), 1–20.

[16] Adriana, M., Cuculeanu, V., 1999. Uses of a decision support system for agricultural management under different climate conditions. In Proceedings of the European Conference on Applications of Meteorology (ECAM99); Norrkping, Sweden, 13–17 September 1999. p. 135.

[17] Kuo, S.F., Lin, B.J., Shieh, H.J., 2001. CropWat model to evaluate crop water requirements in Taiwan. In Proceedings of the 1st Asian Regional Conference of International Commission on Irrigation and Drainage; Seoul, Republic of Korea, 16–21 September 2001. pp. 1–14.

[18] Bryant, K.J., Benson, V.W., Kiniry, J.R., et al., 1992. Simulating corn yield response to irrigation timings: Validation of the EPIC model. Journal of Production Agriculture. 5, 237–242.

[19] Nazeer, M., 2009. Simulation of maize crop under irrigated and rainfed conditions with CropWat model. ARPN Journal of Agricultural and Biological Science. 4, 68–73.

[20] Adriana, M., Cuculeanu, V., 2000. Use of a decision support system for drought impact assessment and Agricultural mitigation options in Romania. In Proceedings of the Central and Eastern European Workshop on Drought Mitigation; Budapest-Felsogod, Hungary, 12–15 April 2000. pp. 259–266.

[21] Hussein, F., Yaqoub, A., Janat, M., 2013. A study of the simulation of the effect of deficit irrigation on cotton crop and evaluation of some alternatives for irrigation management using CropWat program. Damas-

cus University Journal of Agricultural Sciences. 29(1), 343–360.

[22] Allen, R.G., Pereira, L.S., Raes, D., et al., 1998. Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. FAO: Rome, Italy.

[23] Kisekka, I., Aguilar, J.P., Rogers, D.H., et al., 2016. Assessing deficit irrigation strategies for corn using simulation. Transactions of the ASABE. 59(1), 303–317.

[24] Smith, M., Kivumbi, D., Heng, L.K., 2000. Use of the FAO CROPWAT model in deficit irrigation studies. In: Kirda, C., Moutonnet, P., Hera, C., et al. (Eds.). Crop Yield Response to Deficit Irrigation. Kluwer Academic Publishers: Dordrecht, The Netherlands. pp. 17–27.

[25] Thanoun, A., 2019. The effect of irrigation scheduling using the CROPWAT program on water use efficiency, yield and its components of maize *Zea mays* L. in semi-arid areas. Al-Rafidain Engineering Journal. 24(2), 130–137.

[26] Hassoun, N., Kinjo, A., Abbas, J., et al., 2024. Evaluation of water consumption and decrease in productivity of maize crop using CropWat.8. Syrian Journal of Agricultural Research (SJAR). 11(1), 427–444.

[27] Hassan, D., Thamer, T., Mohammed, R., et al., 2023. Calibration and evaluation of AquaCrop model under different irrigation methods for maize (*Zea mays* L.) in central region of Iraq. In: Kallel, A., Barbieri, M., Rodrigo-Comino, J., et al. Selected studies in environmental geosciences and hydrogeosciences. CAJG 2020. Advances in Science, Technology & Innovation. Springer: Cham, Switzerland. DOI: https://doi.org/10.1007/978-3-031-43803-5_10

[28] Mohammed, R.J., Suliman, A.A., 2023. Land Suitability Assessment for Wheat Production Using Analytical Hierarchy Process and Parametric Method in Babylon Province. Journal of Ecological Engineering. 24(7), 75–87.