



Determination of Crop Water Consumption and Irrigation Schedules of Important Crops in Chad

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HIGHLIGHTS

- Chad is an African country rich in soil potential, but also rich in water resources.
- Sesame, maize, cotton, groundnut and tomato plants were discussed in the study.
- Greater irrigation demand was observed in Faya District compared to Am-Timan and Bol.

Abstract

This study aims to determine the crop water consumption (ET_c) and irrigation schedules of some crops grown intensively in these regions, considering the Am-Timan and Bol meteorological stations located in the Sahel and Sudan climatic zones of Chad and the Faya station in the Sahara region. In the study, calculations were made using CropWat 8.0 software developed by the Land and Water Development Department of FAO. The crop coefficients (K_c) of five different crops, namely sesame, maize, cotton, groundnut and tomato, which are the most grown in Chad, and the reference evapotranspiration (ET_o) for the regions were calculated. According to the obtained results, the average reference evapotranspiration (ET_o) values were calculated as 7.38 mm/day for Am-Timan, 10.45 mm/day for Bol and 11.11 mm/day for Faya. The calculated crop water consumption (ET_c) values were 531.6 mm in Am-Timan, 863.7 mm in Bol, and 1080.5 mm in Faya for sesame; 685.1 mm in Am-Timan, 1024.0 mm in Bol, and 1518.2 mm in Faya for maize; 1103.5 mm in Am-Timan, 1877.7 mm in Bol, and 2052.9 mm in Faya for cotton; 532.6 mm in Am-Timan, 742.4 mm in Bol, and 1083.1 mm in Faya for groundnut; and 800.6 mm in Am-Timan, 1211.7 mm in Bol, and 1037.1 mm in Faya for tomato. When irrigation schedules were examined, it was determined that rainfall was adequate for certain crops, including maize and groundnut, in Am-Timan and that there was no need for additional irrigation. However, in Bol and Faya regions, irrigation practices became necessary due to insufficient rainfall. These results emphasize the need to develop region-specific irrigation strategies for effective management of water resources and increased agricultural productivity.

Keywords: Crop Coefficient (K_c); Crop Water Consumption (ET_c); Cropwat; Evapotranspiration (ET_o); Irrigation Schedule

1. Introduction

The demand for water is increasing day by day due to the increase in the world population, and this makes the sustainable management of water resources even more important. Agricultural production is

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the area where water resources are used most intensively both globally and in Turkey. Effective management of water resources depends on the efficient and planned implementation of agricultural irrigation. The effectiveness of irrigation water use is ensured by the construction and effective operation of agricultural infrastructure systems such as land consolidation, irrigation and drainage in areas where irrigated agriculture is carried out. Crop water consumption (ET_c) is a fundamental input in the design and operation of these infrastructures, as well as in drought monitoring studies and the creation of hydrological models. ET_c can vary significantly depending on the climate zone, crop species, crop development stages and applied agricultural techniques, therefore many mathematical models have been developed for the closest estimate to real values (TAGEM and DSI 2017).

Accurate estimation of crop water consumption is a critical element in planning, designing and implementing irrigation projects. Considering the high investment costs of large irrigation systems, consideration of realistic parameters is of crucial to achieve the expected benefits. Deficiencies or incorrect estimations of meteorological parameters can be the main reason for failure of irrigation projects, leading to incorrect dimensioning of projects, inadequate water applications and increased energy consumption. Therefore, sustainability of irrigated agriculture requires practical solutions for crop water consumption data in both planning and operational stages.

Irrigation schedule is a planning process that ensures that crop water requirements are met at the right time and in proper amounts during the growing season. This planning process includes basic elements such as when to irrigate and how much water to give for each irrigation. In irrigated agricultural practices, efficient and sustainable use of water is of crucial. For this purpose, irrigation should be carried out according to a specific program, appropriate irrigation methods (e.g. pan, furrow, sprinkler or drip irrigation systems) should be selected and the technical specifications of the systems to be used in the application should be well known. In addition, it is important that the technical details of the irrigation system used are understood by the producer. An effective irrigation schedule includes information such as the time to start irrigation, irrigation intervals, the amount of water to be given in each irrigation, the total number of irrigations during the season, and the total seasonal water consumption. A rational irrigation program increases the efficiency of irrigation by minimizing water losses; reduces the leaching of nutrients from the soil and therefore fertilization costs; prevents salinity and waterlogging problems in the soil; reduces weed and disease risks, and allows for more efficient use of rainfall. At the same time, it ensures a more equitable distribution of water among farmers and increases yield and quality by meeting the water requirements of the crop at an adequate level. In cases of water shortage, it allows for the irrigation of larger agricultural areas by using the most efficient use of existing water resources. In addition, yield losses that may occur due to excessive irrigation are prevented. In this context, producers need to create a special irrigation schedule for each type of plant they grow. These schedules can be prepared either using ready-made irrigation schedules developed as a result of research and easily applied in practice, or individually with the help of soil analyses and moisture measurement devices. However, the second way is a more complex approach that requires expert support and requires more knowledge and experience in implementation (Topak 2022).

Chad is an agricultural country with rich soil potential, but limited in terms of water resources. A large part of its arable lands needs irrigation. It has been observed that there are limited studies on the planned and efficient use of limited water resources. This research was carried out to calculate the water consumption and irrigation schedules of some important crops grown in the Sahel and Sudan regions of Chad. This study aims to contribute to the development of local capacity by guiding farmers and local government units in protecting and using water resources efficiently. Considering the effects of climate change on water resources, this research aims to help farmers develop more effective irrigation strategies. The limited number of studies conducted using CropWat software in particular led to the planning of this study in order to fill this gap in knowledge and guide farmers in the region in creating modern irrigation schedules.

2. Materials and Methods

Chad is a country located in the center of the African continent, between 7 and 24 degrees north latitude and 13 and 24 degrees east longitude. Its total area is 1,284,000 km², extending approximately 1,700 km from north to south and 1,000 km from east to west (Anonymous 2013; 2020). The capital of Chad is Encemine, and Chad is the fifth largest country in Africa in terms of area. The country borders Libya to the north, Sudan to the east, the Central African Republic to the south, and Cameroon, Nigeria, and Niger to the west. Chad is a landlocked country. (Gauquelin 2008). The location of Chad on the African continent is shown in Figure 1.



Figure 1. Chad's location in the African continent (Anonymous 2025a)

Chad is located in the Sahel zone, which consists of semiarid grassland and shrubland between the Sahara Desert in the north and the tropical savannas in the south. The country is divided into three main climatic zones: the Sahara in the north, the Sahel in the middle, and the Sudan (subtropical) in the south (Figure 2). The southern part consists of forested areas and receives high amounts of rainfall, with pastures and arable lands in this region. Savanna, shrubland, and steppe plants are common in the middle zone. The northern region is covered with deserts and mountains that are not suitable for plant growth (Kavas 2017; Mahamat et al. 2020).



Figure 2. Climatic zones of Chad (Wikitravel 2025)

Chad is a country with distinct climate differences, with a desert climate in the north and a savanna climate in the south. Chad has a geography where hot, temperate and tropical climates coexist. The country lies like a corridor in the middle of Africa, where the transition from desert climate to tropical climate can be easily observed (Kavas 2017).

The northern part of the country consists of the Sahara region, located between 16°-23° north parallels and 15°-24° east meridians. The southern border of this region is determined by the 200 mm precipitation line, which is characterized by extremely low precipitation and is dominated by permanent drought. The

Sahel belt covers an area of 490,570 km², making up one-fourth of the country, and has precipitation ranging from 200 to 800 mm. This region is characterized by a longer dry season, with precipitation decreasing from south to north. The Sudan region in southern Chad covers one-fourth of the country, receiving 800 mm to 1,200 mm of precipitation. This region is the most precipitation-rich region of the country and is characterized by abundant precipitation, exceeding 800 mm per year. The duration of the rainy season is approximately equal to the dry season and lasts about six months. This region has a climate that is quite suitable for agricultural activities (Anonymous 2016).

The southern part of Chad has a tropical climate, with heavy rainfall between May and October. The central part, especially in the north, has an arid and semiarid climate. The Sahara region has a hot climate with little rainfall. The Sahel climate is characterized by a long dry season and a short wet season (Nicholson 1995). Chad's average temperature ranges from 12°C to 50°C (Mahamat et al. 2020).

Approximately 35% of the country's land is meadow and pasture areas, while 55.6% is made up of the Sahara Desert. Currently, agricultural activities are carried out on only 4% of the country's land, which is approximately 5.23 million hectares. The proportion of forested areas is 3.36%. Approximately 38,000 hectares of agricultural land is covered with planted plants consisting of fruit and other trees, while the rest consists of arable land. In addition, approximately 12.4% of agricultural land is left fallow (FAOSTAT 2025).

Chad is a country with limited water resources, and its water resources consist of lakes and streams. The most important water source is Lake Chad. The Shari River and its important tributary Logon, coming from the south of the country, carry water to Lake Chad (Kabataş and Büyükbayraktar 2022; Anonymous 2025b). Chad's annual river potential is around 44 billion m³ (AQUASTAT 2023). It has significant groundwater resources throughout the country, and the usable water potential of large aquifers is estimated between 260 billion and 540 billion m³ (Bouyebri 2022). Considering Chad's current population (16,425,000 people) and annual renewable total water resources potential (55.7 billion m³), the amount of water per capita is calculated as approximately 2750 m³.

Chad is an agricultural country where the agricultural sector employs more than 75% of the total labour force (Yacoub 2021). Data on the production areas and production quantities of the crops grown in Chad are compiled from the FAOSTAT (2025) database and presented in Table 1. Accordingly, the main crops in terms of production area in 2023 are sorghum, millet, groundnut, cereals, sesame and maize. The leading crops in terms of production quantity were sorghum, groundnut, millet, cereals and Jerusalem artichoke. When we look at the crop yields, it is seen that the yields of the products grown in the country are generally low.

Table 1. Production areas and production quantities of crops commonly grown in Chad (FAOSTAT 2025).

Crops	2017		2023		Crop Yield (tonnes/ha)
	Production Area (ha)	Production Quantity (tonnes)	Production Area (ha)	Production Quantity (tonnes)	
Sorghum	1147470	946295	1103688	877520	0.795
Millet	1165459	660175	1139479	634079	0.556
Groundnut	768056	870094	749372	782177	1.044
Cereals	451873	448500	486333	552226	1.135
Sesame	297654	158715	396231	209884	0.529
Maize	335637	396506	320540	354241	1.105
Cottonseed	120000	54545	195000	102474,72	0.525
Dry bean	209309	151974	223197	150123	0.672
Rice	191029	263555	175489	223952	1.128
Jerusalem artichoke	48088	461079	48953	469480	9.590
Melon seed	35169	24094	35973	24617,49	0.684
Cassava	35194	290584	34934	288345	8.254

Chad has 39 million hectares of potential arable land, covering 30% of its national territory, of which approximately 5.6 million hectares are irrigated. Approximately 335,000 hectares of this irrigated area can be easily irrigated (Anonymous 2013). Chad has irrigated approximately 40,000 hectares of agricultural

land since its independence. According to a 2015 study by FAO, 78% of existing irrigated agricultural projects in the country have come to a standstill, while 23% are operating with very low yields (Anonymous 2018).

In the calculation of crop water consumption (ET_c) values in the CropWat software, crop coefficient (K_c) values of the crops specified in the study were needed. Crop coefficient values were determined and corrected using the crop coefficient approach defined by Allen et al. (1998). Three K_c values were used to construct the K_c graphic; early development period (K_{Cini}), mid-season period (K_{Cmid}) and late season period (K_{Cend}). It was assumed that the K_c coefficients were constant in early development and mid-season periods. The K_c values of the crop early development period and late season periods were determined graphically according to the method specified by Allen et al. (1998).

In calculating the early development period crop coefficient (K_{Cini}) values, the following equation was used according to the approach suggested by Allen et al. (1998). The parameter in the graphs shown in Figure 3 and Figure 4, specified between 1 and 20 days, indicates the average number of rainy days per week. For each region, when this parameter is combined with the ET₀ values calculated in the CropWat software and located on the X axis of the graphs, the K_{Cini} values (K_{Cini} (Figure 3) and K_{Cini} (Figure 4)) located on the Y axis of the graph are found. Depending on whether the soil structure is coarse-textured or medium and fine-textured, graphs (a) or (b) in Figure 4 were used. Using the average infiltration depth values, the K_{Cini} values for each region are calculated using the equation below.

$$K_{Cini} = K_{Cini}(\text{Figure 3}) + \frac{(I-10)}{(40-10)} [K_{Cini}(\text{Figure 4}) - K_{Cini}(\text{Figure 3})] \tag{1}$$

K_{Cini}(Figure 3)= K_{Cini} value in Figure 3

K_{Cini}(Figure 4)= K_{Cini} value in Figure 4.

I= Average infiltration depth (mm).

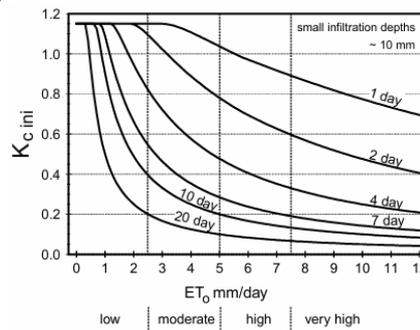


Figure 3. Average early development period K_c values for all soil types (Allen et al., 1998)

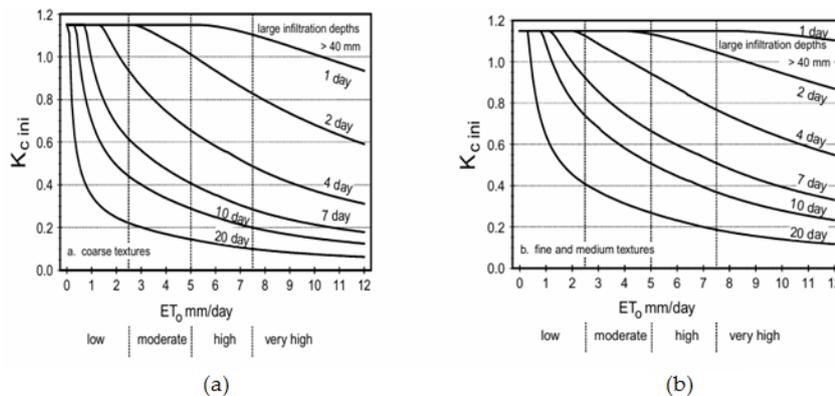


Figure 4. Average early development period K_c values according to soil texture, a) coarse-textured soils; b) medium and fine-textured soils (Allen et al., 1998)

K_c values for the mid-season period (K_{Cmid}) are determined using the following equation suggested by (Allen et al., 1998).

$$K_{Cmid} = K_{Cmid}(Tab) + [0,04 (U_2 - 2) - 0,004 (RH_{min} - 45)](h/3)^{0,3} \quad (2)$$

$K_{Cmid}(Tab)$ = K_{Cmid} value in Table 2

U_2 = Average wind speed (m/sn)

RH_{min} = Daily average minimum relative humidity (%)

h = Maximum plant depth (m)

The calculation for the late season period K_c values (K_{Cend}) is calculated with the following equation (Allen et al., 1998).

$$K_{Cend} = K_{Cend}(Tab) + [0,04 (U_2 - 2) - 0,004 (RH_{min} - 45)](h/3)^{0,3} \quad (3)$$

$K_{Cend}(Tab)$ = K_{Cend} value in Table 2

U_2 = Average wind speed (m/sn)

RH_{min} = Daily average minimum relative humidity (%)

h = Maximum plant depth (m)

Table 2. Mid-season and late season period crop coefficient values (K_{Cmid}) of the crops considered in the study (Allen et al., 1998)

Crop	K_{Cmid}	K_{Cend}
Groundnut	1.15	0.60
Cotton	1.20	0.50
Sesame	1.10	0.25
Maize	1.20	0.60
Tomato	1.15	0.70

In order to calculate the reference evapotranspiration (ET_o) and crop coefficients (K_c), climatic data were obtained from Am-Timan, Bol and Faya meteorological stations. Am-Timan, Bol and Faya regions are located in Sudan, Sahel and Sahara zones respectively. The required climatic parameters are temperature (maximum and minimum), precipitation, humidity (maximum and minimum), radiation, sunshine duration, wind speed and number of rainy days on monthly basis. CropWat software was used to calculate the reference evapotranspiration (ET_o) and crop water consumptions (ET_c) of sesame, maize, cotton, groundnut and tomato crops for Am-Timan, Bol and Faya regions.

3. Results and Discussion

3.1. Reference Evapotranspiration (ET_o) Results

In calculating the reference evapotranspiration (ET_o), monthly average minimum and maximum temperature, humidity, wind speed and sunshine duration climate data were used. The values calculated by Cropwat software for Am-Timan, Bol and Faya regions are given in Table 3. Accordingly, annual average ET_o values for Am-Timan, Bol and Faya regions were 7.38 mm/day, 10.45 mm/day and 11.11 mm, respectively. While the highest ET_o value for Am-Timan was 9.84 mm/day in March, the lowest value was calculated as 4.55 mm/day in August. The highest ET_o value for Bol was calculated as 13.42 mm/day in April and the lowest value was calculated as 6.31 mm/day in August. While the highest ET_o value for Faya was calculated as 13.77 mm/day in May, the lowest value was calculated as 7.72 mm/day in December.

Table 3. Annual average ETo values for Am-Timan, Bol and Faya regions

Months	Annual average ETo values (mm/day)		
	Am-Timan	Bol	Faya
January	7.91	9.64	8.04
February	8.94	11.55	9.75
March	9.84	13.01	11.48
April	9.68	13.42	12.70
May	8.82	12.87	13.77
June	7.03	10.85	13.48
July	5.50	8.52	12.83
August	4.55	6.31	11.59
September	4.98	8.20	11.87
October	6.03	10.53	10.82
November	7.69	10.98	9.33
December	7.54	9.48	7.72
Total	7.38	10.45	11.11

3.2. Effective Precipitation Values

Long-term monthly average precipitation data for Am-Timan were obtained from the relevant meteorological station, while values for Bol and Faya were obtained from ClimateData (2025). To calculate the crop irrigation water requirement, precipitation data were entered into the Cropwat software and effective precipitation values were calculated. Annual average precipitation and effective precipitation values for the regions are given in Table 4. The average annual precipitation values for Am-Timan, Bol, and Faya are 910.5 mm, 223.0 mm, and 6.0 mm, respectively.

Table 4. Annual average precipitation and effective precipitation for Am-Timan, Bol and Faya regions

Months	Am-Timan		Bol		Faya	
	Precipitation (mm)	Effective Precipitation (mm)	Precipitation (mm)	Effective Precipitation (mm)	Precipitation (mm)	Effective Precipitation (mm)
January	0.0	0.0	0.0	0.0	0.0	0.0
February	0.0	0.0	0.0	0.0	0.0	0.0
March	0.0	0.0	0.0	0.0	0.0	0.0
April	17.7	17.2	0.0	0.0	0.0	0.0
May	63.0	56.6	7.0	6.9	0.0	0.0
June	135.9	106.3	11.0	10.8	0.0	0.0
July	222.0	143.1	61.0	55.0	2.0	2.0
August	261.7	151.2	104.0	86.7	4.0	4.0
September	166.0	121.9	36.0	33.9	0.0	0.0
October	44.2	41.1	4.0	4.0	0.0	0.0
November	0.0	0.0	0.0	0.0	0.0	0.0
December	0.0	0.0	0.0	0.0	0.0	0.0
Total	910.5	637.5	223.0	197.4	6.0	6.0

3.3. Crop Coefficient (Kc) Results

Table 5 shows the results of crop coefficients (K_{Cini} , K_{Cmid} , K_{Cend}) for sesame, maize, cotton, groundnut and tomato calculated for different meteorological stations. The crop coefficient equations ((1), (2), (3)) specified in the Materials and Methods section were applied for each crop and region to obtain the results in the table.

The average infiltration depth values (I) in Equation (1) are taken as 30 mm for the Am-Timan and Bol regions and 40 mm for the Faya region. The average number of rainy days per week values required to calculate the K_{Cini} are calculated as 2.48 days/week, 1.12 days/week, and 0.25 days/week for Am-Timan, Bol,

and Faya, respectively. These values are combined with the total ET_o values (7,38 mm/day, 10,45 mm/day and 11,11 mm/day) calculated for each region in Table 3 to obtain the K_{Cini} (Figure 3) and K_{Cini} (Figure 4) values. Thus, since the values of all parameters in Equation (1) have been determined for each region, the K_{Cini} values are calculated and are given in Table 5.

The average wind speed (U_2) values in Equation (2) and Equation (3) were 2.8 m/s, 5.5 m/s, and 5.6 m/s for the Am-Timan, Bol, and Faya regions, respectively, and the daily average minimum relative humidity (RH_{min}) values were 43%, 31%, and 17%, respectively. The maximum plant depth (h) lengths were 0.4 m, 1.5 m, 1 m, 2 m, and 0.6 m for groundnut, cotton, sesame, maize, and tomato, respectively. Using these values and those given in Table 2, the K_{Cmid} and K_{Cend} values were found and are given in the table.

K_{Cini} values were the same for all crops in the same region. Since the region with the highest number of rainy days per week was Am-Timan, the K_{Cini} values were the highest here, while the Faya region had the lowest number of rainy days per week, so the K_{Cini} values were also low. There were no major differences between the K_{Cmid} values of the crops. K_{Cend} values increased gradually from Am-Timan to the Faya region.

Table 5. Annual average ET_o values for Am-Timan, Bol and Faya regions

Crop	K_C	Am-Timan	Bol	Faya
Sesame	K_{Cini}	0.77	0.40	0.06
	K_{Cmid}	1.13	1.24	1.28
	K_{Cend}	0.28	0.39	0.43
Maize	K_{Cini}	0.77	0.40	0.06
	K_{Cmid}	1.24	1.37	1.43
	K_{Cend}	0.64	0.77	0.83
Cotton	K_{Cini}	0.77	0.40	0.06
	K_{Cmid}	1.23	1.36	1.41
	K_{Cend}	0.25	0.66	0.71
Groundnut	K_{Cini}	0.77	0.40	0.06
	K_{Cmid}	1.17	1.26	1.29
	K_{Cend}	0.62	0.70	0.74
Tomato	K_{Cini}	0.77	0.40	0.06
	K_{Cmid}	1.17	1.27	1.31
	K_{Cend}	0.72	0.82	0.86

3.4. Crop Water Consumption (ET_c) and Irrigation Schedules for Am-Timan

For the Am-Timan region, the monthly crop water consumptions (ET_c) of sesame, maize, cotton, groundnut and tomato crops calculated in the CropWat software are given in Table 6. The table also provides the effective precipitation (EP) and irrigation water requirements (IWR) of the crops, along with their planting and harvest dates. ET_c values for sesame, maize, cotton, groundnut and tomato plants are 531.6 mm, 685.2 mm, 1103.8 mm, 532.7 mm and 800.7 mm, respectively. The lowest ET_c for sesame is November with 2.0 mm, while the highest is September with 168.7 mm. The lowest ET_c for maize is November with 10.8 mm, while the highest is July with 187.2 mm. The lowest ET_c for cotton is June with 82.7 mm, while the highest ET_c for cotton is October with 231.0 mm. The lowest ET_c for groundnut is June with 82.7 mm, while the highest ET_c for groundnut is August with 165.3 mm. The lowest ET_c for tomato is September with 120.9 mm, while the highest ET_c for peanut is November with 278.8 mm.

Table 6. ET_c values of sesame, cotton, maize, groundnut and tomato crops for Am-Timan (mm)

Crops		Months							Total
		June	July	August	September	October	November	December	
Sesame (15/07 - 01/11)	ET _c	-	69.3	131.8	168.7	159.8	2.0	-	531.6
	EP ¹	-	78.9	151.1	121.8	41.1	0.0	-	392.9
	IWR ²	-	0.9	4.3	46.8	118.6	2.0	-	172.6
Maize (01/06 - 03/10)	ET _c	167.6	187.2	174.6	145	10.8	-	-	685.2
	EP	106.2	143.1	151.1	121.8	6.4	-	-	528.6
	IWR	61.2	44.0	23.4	23.3	0.1	-	-	152.0
Cotton (15/06 - 26/12)	ET _c	82.7	139.8	152.9	184.6	231.0	220.1	92.7	1103.8
	EP	61.5	143.1	151.1	121.8	41.1	0.1	0.0	518.7
	IWR	24.6	2.2	10.5	62.8	189.9	219.9	92.7	602.6
Groundnut (15/06 - 27/09)	ET _c	82.7	158.3	165.3	126.4	-	-	-	532.7
	EP	61.5	143.1	151.1	111.8	-	-	-	467.5
	IWR	24.6	15.3	14.9	12.3	-	-	-	67.1
Tomato (01/09 - 24/12)	ET _c	-	-	-	120.9	214.1	278.8	186.9	800.7
	EP	-	-	-	121.8	41.1	0.1	0	163.0
	IWR	-	-	-	12.1	172.9	278.6	186.9	650.5

¹ EP= Effective Precipitation (mm), ² IWR= Irrigation Water Requirement (mm)

Irrigation schedules of the crops were determined by Cropwat software and are given in Table 7. The table includes the monthly net irrigation water amounts (NIW) of the crops and the total irrigation numbers (IN). In the Am-Timan region, it has been calculated that sesame needs to be irrigated 1 time, cotton 4 times and tomatoes 8 times. The months in which irrigation will be applied are October, November and December. Since effective rainfall is sufficient during the growing season, there is no need for irrigation for corn and groundnut crops.

Table 7. Irrigation schedules of sesame, cotton, maize, groundnut and tomato crops for Am-Timan

Crops		Months			Total
		October	November	December	
Sesame	NIW ¹	117.6	-	-	117.6
	IN ²	1	-	-	1
Maize	NIW	-	-	-	-
	IN	-	-	-	-
Cotton	NIW	239.0	136.0	156.6	531.6
	IN	2	1	1	4
Groundnut	NIW	-	-	-	-
	IN	-	-	-	-
Tomato	NIW	141.2	312.1	166.1	619.4
	IN	2	4	2	8

¹ NIW= Net Irrigation Water (mm), ² IN= Irrigation number

3.5. Crop Water Consumption (ET_c) and Irrigation Schedules for Bol

For the Bol region, the monthly crop water consumptions (ET_c) of the crops are given in Table 8. ET_c values for sesame, maize, cotton, groundnut and tomato plants are 863,9 mm, 1024,1 mm, 1877,7 mm, 742,4 mm and 1211,7 mm, respectively. The lowest ET_c for sesame is November with 4.3 mm, while the highest is October with 328,2 mm. The lowest ET_c for maize is October with 25,2 mm, while the highest is July with 292,1 mm. The lowest ET_c for cotton is June with 66,4 mm, while the highest ET_c for cotton is October with 465,4 mm. The lowest ET_c for groundnut is June with 66,4 mm, while the highest ET_c for groundnut is August with 252,1 mm. The lowest ET_c for tomato is September with 114,9 mm, while the highest ET_c for peanut is November with 446,6 mm.

Table 8. ET_c values of sesame, cotton, maize, groundnut and tomato crops for Bol (mm)

Crops		Months							Total
		June	July	August	September	October	November	December	
Sesame (15/07 - 01/11)	ET _c	-	54.8	156.3	320.3	328.2	4.3	-	863.9
	EP ¹	-	33.5	86.6	34.1	4.1	0.0	-	158.3
	IWR ²	-	23.0	69.6	286.3	324.1	4.3	-	707.3
Maize (01/06 - 03/10)	ET _c	145.6	292.1	276.7	284.5	25.2	-	-	1024.1
	EP	10.9	54.9	86.6	34.1	1.2	-	-	187.7
	IWR	134.8	237.1	190.0	250.4	23.3	-	-	835.6
Cotton (15/06 - 26/12)	ET _c	66.4	130.5	213.7	354.1	465.4	414.5	233.1	1877.7
	EP	8.3	54.9	86.6	34.1	4.1	0.1	0	188.1
	IWR	58.3	75.5	127.1	320.1	461.4	414.3	233.1	1689.8
Groundnu t (15/06 - 27/09)	ET _c	66.4	195.0	252.1	228.9	-	-	-	742.4
	EP	8.3	54.9	86.6	31.9	-	-	-	181.7
	IWR	58.3	140.1	165.5	195.0	-	-	-	558.9
Tomato (01/09 - 24/12)	ET _c	-	-	-	114.9	381.5	446.6	268.7	1211.7
	EP	-	-	-	34.1	4.1	0.1	0	38.3
	IWR	-	-	-	80.8	377.5	446.4	268.7	1173.4

¹ EP= Effective Precipitation (mm), ² IWR= Irrigation Water Requirement (mm)

Irrigation schedules of the crops are given in Table 9. While the number of irrigations for sesame, maize and groundnut is 5, for cotton it is 10 and for tomatoes it is 12. The times when irrigation is concentrated for plants are between September and November.

Table 9. Irrigation schedules of sesame, cotton, maize, groundnut and tomato crops for Bol

Crops		Months							Total
		June	July	August	September	October	November	December	
Sesame	NIW ¹	-	-	-	248.8	393.7	-	-	642.5
	IN ²	-	-	-	2	3	-	-	5
Maize	NIW	81.9	273.9	152.6	172.1	-	-	-	680.5
	IN	1	2	1	1	-	-	-	5
Cotton	NIW	45.6	-	91.5	421.5	409.6	430.7	152.4	1551.3
	IN	1	-	1	3	3	3	1	12
Groundnu t	NIW	-	159.0	107.2	224.0	-	-	-	490.2
	IN	-	2	1	2	-	-	-	5
Tomato	NIW	-	-	-	59.6	326.0	476.7	265.8	1128.1
	IN	-	-	-	1	3	4	2	10

¹ NIW= Net Irrigation Water (mm), ² IN= Irrigation number

3.6. Crop Water Consumption (ET_c) and Irrigation Schedules for Faya

For the Faya region, the monthly crop water consumption (ET_c) of the crops are given in Table 10. ET_c values for sesame, maize, cotton, groundnut and tomato plants are 1080,5 mm, 1518,2 mm, 2053,0 mm, 1083,3 mm and 1037,1 mm, respectively. Since the Faya region receives very little annual rainfall, ET_c values (except for tomatoes) was higher than the other two regions. Irrigation water requirement values was also very close to ET_c values.

Table 10. ET_c values of sesame, cotton, maize, groundnut and tomato crops for Faya (mm)

Crops		Months							Total
		June	July	August	September	October	November	December	
Sesame (15/07 - 01/11)	ET _c	-	12.8	224.8	478.7	360.0	4.2	-	1080.5
	EP ¹	-	1.3	3.9	0.1	0.0	0.0	-	5.3
	IWR ²	-	11.6	220.8	478.6	360.0	4.2	-	1075.2
Maize (01/06 - 03/10)	ET _c	54.4	436.8	547.7	447.8	31.5	-	-	1518.2
	EP	0.1	2.0	3.9	0.1	0.0	-	-	6.1
	IWR	54.3	434.8	543.8	447.7	31.5	-	-	1512.1

Cotton	ET _c	12.9	78.5	363.8	529.2	498.9	370.4	199.3	2053.0
(15/06 -	EP	0.1	2.0	3.9	0.1	0.0	0.0	0.0	6.1
26/12)	IWR	12.7	76.6	359.9	529.1	498.9	370.4	199.3	2046.9
Groundnut	ET _c	12.9	226.5	483.5	360.4	-	-	-	1083.3
t (15/06 -	EP	0.1	2.0	3.9	0.1	-	-	-	6.1
27/09)	IWR	12.7	224.6	479.5	360.3	-	-	-	1077.1
Tomato	ET _c				49.6	371.7	390.1	225.7	1037.1
(01/09 -	EP				0.1	0.0	0.0	0.0	0.1
24/12)	IWR				49.5	371.7	390.1	225.7	1037.0

¹ EP= Effective Precipitation (mm), ² IWR= Irrigation Water Requirement (mm)

Irrigation schedules of the crops are given in Table 11. In the Faya region, the number of irrigations of the crops increased considerably compared to the other two regions. In some months, the irrigation interval was reduced to 2 days.

Table 11. Irrigation schedules of sesame, cotton, maize, groundnut and tomato crops for Faya

Crops		Months							Total
		June	July	August	September	October	November	December	
Sesame	NIW ¹	-	-	233.4	463.0	339.4	-	-	1035.8
	IN ²	-	-	8	11	9	-	-	28
Maize	NIW	42.9	446.8	530.0	440.4	-	-	-	1460.1
	IN	2	13	15	10	-	-	-	40
Cotton	NIW	-	64.9	357.1	559.1	452.6	395.5	152.0	1981.2
	IN	-	2	7	8	7	6	2	32
Groundnut	NIW	12.7	224.8	468.0	345.2	-	-	-	1050.7
	IN	1	10	15	12	-	-	-	38
Tomato	NIW	-	-	-	49.4	371.7	389.5	195.4	1006.0
	IN	-	-	-	4	15	15	6	40

¹ NIW= Net Irrigation Water (mm), ² IN= Irrigation number

K_{Cini} values for crops in the Faya region were significantly lower than in the Am-Timan and Bol regions, and the ET_c values for crops in Faya during the planting month were lower than in other regions. Since rainfall in the Faya region is quite low and the annual average ET_c value is higher than in other regions, the total ET_c values of crops other than tomatoes reached the highest value. Since there was low rainfall in the Bol region during the months when tomatoes were grown and the K_{Cini} value for the crop remained low in Faya, only the tomato plant was calculated with a higher value than Faya in the Bol region.

Limited water resources, especially in arid and semiarid regions, make irrigation management and scheduling critical. Improper irrigation scheduling can lead to crop yield loss, lower groundwater levels, or salinity problems. Monitoring irrigation schedules with precise measurement and monitoring systems is crucial for agricultural sustainability. In this regard, software like CropWat not only simplifies operations by providing accurate data on irrigation water amount and schedules, but also offers advantages in terms of water conservation. CropWat software was also used in studies conducted in regions similar to Chad. Some et al. (2006) analyzed crop water use and soil water balance using CropWat software in Burkina Faso. In their study, they stated that water deficit is experienced towards the end of the rainy season in Sudano Sahel and Sahel regions and irrigation requirement is higher. Rose et al. (2019) modeled crop water requirement and irrigation schedule using CropWat software for rice production in Eastern Province of Rwanda. Herrero Batalla and Uriach Parellada (2014) also analyzed water requirements of basic agricultural products in seven districts of Rwanda using CropWat software. Mal and Sen (2025) used CropWat software to determine irrigation water requirements and irrigation schedules for tomatoes and soybeans in Chandrapur, India. The results suggest that it can help producers, researchers, and policymakers implement more effective irrigation management in water-scarce regions. Haj-Amor et al. (2020) used CropWat software to calculate the net irrigation requirement (NIR) of the date palms in order to investigate the effects of climate change on the irrigation water requirement of date palm trees in

Tunisian conditions. Moseki et al. (2019) determined the crop water requirement and irrigation schedule of *Jatropha curcas* L. in semiarid conditions of Botswana using CropWat. The study shows that providing sufficient water to *Jatropha* during the late developmental stage has a much greater impact than during other developmental stages. This suggests that, particularly in semiarid climates, proper planning and timing of planting dates to coincide with high rainfall months is crucial for water resource management.

4. Conclusions

Crop water consumption (ET_c) is one of the most fundamental elements in irrigation applications and is the primary data source for planning, designing and implementing irrigation projects. If the amount of water required by crops is not determined correctly, the effectiveness of irrigation investments and the long-term sustainability of the projects may be seriously jeopardized. Therefore, many methods and numerical models have been developed to estimate crop water requirements based on different meteorological parameters. In this study, the crop water consumption values and irrigation schedules of the main crops grown in the Sahel, Sudan and Sahara climate zones of Chad were evaluated by taking into account the Am-Timan and Bol and Faya meteorological stations. In the study, water consumption of sesame, maize, cotton, groundnut and tomato crops was calculated using the CropWat software and appropriate irrigation schedules were created for these crops.

When the crop water consumption values were examined, the highest values were observed in Faya region, followed by Bol and Am-Timan regions, respectively. The highest crop water consumption (ET_c) of sesame was calculated as 1080.5 mm in Faya, followed by 836.7 mm in Bol and 531.6 mm in Am-Timan. The highest ET_c value for maize was again determined as 1518.2 mm in Faya, and was calculated as 1024 mm and 685.1 mm in Bol and Am-Timan, respectively. The ET_c values of cotton are 2052.9 mm, 1877.7 mm and 1103.5 mm for Faya, Bol and Am-Timan, respectively. The ET_c values of groundnut were calculated as 1083.1 mm in Faya, 742.4 mm in Bol and 532.6 mm in Am-Timan. The highest ET_c value for tomato was calculated as 1211.7 mm in Bol, 1037.1 mm in Faya and 800.6 mm in Am-Timan.

When the irrigation program was evaluated, it was determined that the amount of rainfall was adequate for some plants (such as corn and peanuts) in the Am-Timan region and therefore there was no need for additional irrigation. However, due to insufficient rainfall in the Bol and Faya regions, irrigation applications became mandatory. Otherwise, it is predicted that there may be serious decreases in product yield in the Bol region and that agricultural production may not be possible in the Faya region. Therefore, it would be more appropriate to prefer the southern parts of the country for the cultivation of these plants. In the Sahel and Sahara regions, the cultivation of these plants can only be possible with irrigation applications, and especially the improvement of the soil structure is of crucial. Irrigation alone may not be sufficient due to the sandy soil structure that prevails especially in the Sahara belt; soil reclamation is mandatory for effective agricultural activities in these regions. However, such applications may require quite high costs. In this context, the relevant state institutions should directly intervene in the process and develop supportive policies.

On the other hand, only three meteorological stations (Am-Timan, Bol and Faya) representing the three different climate zones of Chad were taken into account in this study. Therefore, additional studies covering more stations and product data are needed to increase the general ability of the findings and to be able to comparatively evaluate the products and meteorological conditions in different regions.

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