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ESTIMATION OF CROP WATER REQUIREMENT FOR TOMATO PLANT IN AFGOYE-SOMALIA, USING CROPWAT 8.0 MODEL

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Abstract: Crop water requirement or crop evapotranspiration is a vital parameter for irrigation, and it is necessary to determine the quantity of water to be applied for irrigation and develop an effective irrigation schedule. CROPWAT 8.0, decision-support computer software developed by the United Nations Food Agriculture Organization, is used to calculate crop water requirements. In this paper, the CROPWAT 8.0 model was used to estimate the water requirements of tomato crops in Afgoye. The model estimated that the reference evapotranspiration throughout the year reaches 1927.6 mm and the daily reference evapotranspiration is 5.29 mm. The total annual rainfall reaches 584.0 mm with an effective rainfall of 511.1 mm. The total crop evapotranspiration during the growing period was estimated at 678.2 mm and the total irrigation amount was calculated as 452.3 mm with an effective rainfall of 230.6 mm. During the growing period, the net and gross irrigation reaches 392.9 and 561.3 mm respectively. Field experiments should be conducted in the same season and cropping patterns to validate the accuracy of the crop water requirement prediction.

Keywords: CROPWAT 8.0, Tomato, Crop water requirement, Irrigation scheduling

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1. Introduction

Water resources are becoming scarce, particularly in arid and semi-arid climate zones, owing to their potential uses in various sectors. On the other hand, the demand for food, fiber, and forage is increasing due to the increase in the world population, which is predicted to reach 10 billion in the mid-century (Halimi and Tefera, 2019). This has led to the enhancement of agricultural production to meet the needs of large populations and the requirement of fresh water by water users is continually increasing (Eshete et al., 2020). In developing countries, more than 70% of the available freshwater is used for irrigation to achieve optimal agricultural production (FAO, 2017; Michelon et al., 2020; Solangi et al., 2022). Irrigation is an artificial means of supplying water to crops and sometimes supplementing rainwater, where rainfall alone cannot support crop growth and optimal yield production (Waller and Yitayew, 2015). As some regions of the world are facing severe water scarcity, appropriate irrigation practices are the only way to improve the exploitation of available water and increase or avoid causing a reduction in agricultural production. Irrigation engineers, agronomists, and researchers have conducted several studies and continue to focus on irrigation and its governing factors, including plants, soil, water, and atmospheric or climatic characteristics (Liu et al., 2021; Tong et al., 2022; Yerli et al., 2022). Investigating the relationship between plants and water while considering the physical characteristics of the soil and climate enables researchers to boost their understanding of irrigation, which leads to the efficient use of water and saves a significant amount of water that can be used for other purposes. More than 90% of the water used for irrigation or rainwater is lost through evapotranspiration, and a small portion of the water supplied is utilized by crops to carry out metabolic activities for growth and production. (Sterling, 2005) Therefore, understanding crop water requirements, referred to as evapotranspiration, is vital for irrigation. Evapotranspiration is the combination of evaporation, the quantity of water vaporized by solar energy from a bare soil surface or open water body, and transpiration, the amount of water lost by the plant through its leaf stomata (Allen et al., 1998). Climate and micrometeorological characteristics, plant variety, and soil moisture influence evapotranspiration rates. Considering all these factors, evapotranspiration can be used as a tool to minimize water loss resulting from poor irrigation and agronomic practices. According to the Köppen climate classification method, Somalia is characterized by an arid and semi-arid climate zone, and precipitation is high in semi-arid climate regions, mainly in southern regions, while potential evapotranspiration is high in northern Somalia. The country was severely affected by recurrent droughts resulting from erratic rainfall in both the northern and southern regions, lower-level river streams in riverine agricultural lands, and the dry running of boreholes and shallow wells in many inland regions. Therefore, the quantity of water that would be used for irrigation and the amount of rainfall that would be utilized for rainfed farming are both below average and cannot support crop production. According to SWALIM and FAO, the paper on Somali Climate, there is a higher imbalance in water in Somalia: the annual potential evapotranspiration (PET) exceeds the incoming precipitation, indicating that crops experience water stress at their canopy development stages (Muchiri, 2007). Therefore, crop irrigation is necessary during critical water-stress situations.

In Somalia, tomatoes are grown under irrigation regimes, rainfall, and water recessions resulting from floods in the Juba and Shebelle regions. Tomatoes are consumed as soup with sauces, staple dish cereals, or starchy foods by households in agricultural villages and urban areas. The local cherry, Shalambood, Roma VF San Marzano, and Moneymaker varieties are the main tomato cultivars used for growth in Somalia. These tomato cultivars are selectively grown in different climate zones, considering their tolerance to drought and their resistance to pests, insects, and diseases (Abukar, 2004). There are many other recently imported exotic varieties; however, there is no information on their adaptability and production. In the country, there is no available literature and studies focused on the ETc of tomatoes or other vegetables and cereals, except for a few observational studies and reviews (Basnyat, 2007; Ibrahim et al., 2020). Similarly, there is no available literature that focuses on irrigation schedules and crop water requirements. Therefore, this paper aimed to estimate the crop and irrigation water requirements of Tomatoes at Afgoye and develop an irrigation schedule in the 'Xagaa' (summer) season by using the FAO CROPWAT 8.0 model version. The CROPWAT 8.0 model is an irrigation software developed by FAO for quantifying crop water requirements using the Penman-Monteith method. This model can also be utilized for projecting future irrigation water demand (Sunil et al., 2021; Mana et al., 2023).

2. Materials and Methods

2.1. Study Area

Afgoye is located 30 km (18 miles) in western Mogadishu, the Somali capital city. It is well known for its alluvial soil and the Shebelle River, which runs at the center of the town. The study area lies at a latitude of 2° 15'N and a longitude of 45°15E, with an altitude of 83 m. The climate of the town is semi-arid; the annual maximum, minimum, and mean temperatures were recorded as 32.7 °C, 22.1 °C, and 27.3 °C, respectively, and the annual rainfall is 584 mm (Muchiri, 2007). The highest rainfall season occurs from April to Jun and the short rainfall season occurs in October and November (Musei et al., 2021). The soil is black-clayed, and crops such as bananas, cereals (mainly maize), sesame, citrus, and vegetables are grown. Most crops are irrigation-dependent, rainfall is a supplement to irrigation, and it sometimes becomes an alternative when the level of the river's flow is low and irrigation cannot be supported, particularly in farms located far away from the river.

2.2. CROPWAT 8.0 Model Description

The CROPWATT 8.0, irrigation software developed by the Department of Land and Water Resource Management of FAO, is the model used for computing the reference evapotranspiration (ETo), crop water requirements, and irrigation water requirements. According to the FAO, the model also enables the development of irrigation schedules for various management conditions and determines the water supply scheme for different cropping patterns. The model requires meteorological data that is, minimum and maximum temperatures, average relative humidity, wind speed at 2 m in height, and daylight hours, to quantify radiation and reference evapotranspiration. The model also requires rainfall data, crop data such as root depth, the coefficient of crop evapotranspiration (K_c), and soil data for determining crop and irrigation water requirements and crop evapotranspiration. This model with CLIMWAT 2.0 database can also be used when local meteorological data are limited (https://www.fao.org/land-water). CROPWATT 8.0, which was calibrated by comparing the daily prediction of evapotranspiration with Class A pan evaporation and evapotranspiration measured with gauges in the United States, indicates that evapotranspiration computed with CROPWAT 8.0, is reliable.

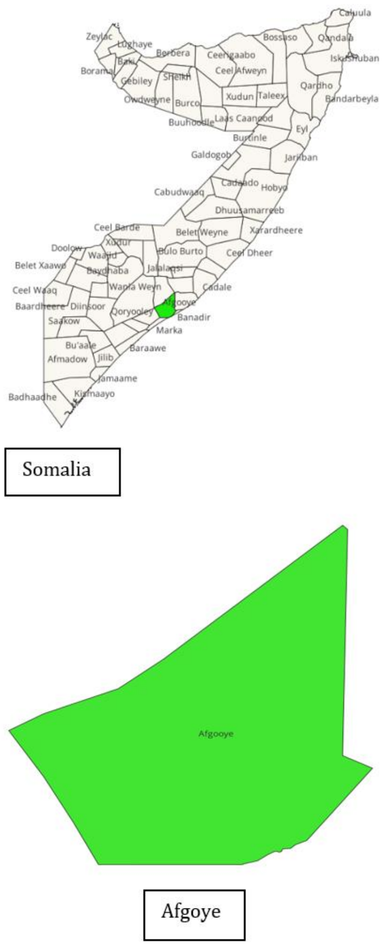

Figure 1. Study area.

CROPWAT 8.0 is also a good decision-making support system for farmers to evaluate irrigation practices in both irrigation and rain-fed farming (Trivedi et al., 2018). Although there are no ready data in meteorological stations in the study area, the climate, soil, and crop data used in this study were E from the FAO CLIMWAT database in between 1975 to 2006). CROPWAT 8.0, was developed from two FAO publications on drainage and irrigation series: FAO-56 “Crop Evapotranspiration-Guidelines for Computing Water Requirement” and FAO-33 “Yield Response to Water” (Allen et al., 1998; Doorenbos et al., 1980).

2.3. Reference Evapotranspiration (ETo)

The CROPWAT program first calculates ETo using the FAO Penman-Monteith method (Allen et al., 1998). This method was developed from a combination of the Penman and Monteith methods and can be applied at various locations. FAO Penman-Monteith method had become one of the equation methods used by researchers, and irrigation engineers to determine irrigation schedules and also predicting for future crop and irrigation water demand (Equation 1).

$$ET_O = \frac{0.408\Delta\ (R_n - \mathrm{G}) + \gamma\ \dfrac{900}{T+273} u_n (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_n)} \quad (1)$$

Where ET_o is; reference evapotranspiration (mm/day), R_n; net radiation at crop surface (MJ m^{-2} day^{-1}), G; soil heat flux density (MJ m^{-2} day^{-1}) mean air temperature with 2 m height, u_2; wind speed at 2 m height (m s^{-1}), e_s; saturation vapor pressure, e_a; actual vapor pressure (kPa), e_s-e_a; saturation vapor pressure deficit (kPa) Δ; slope vapor pressure curve (kPa °C^{-1}), γ; psychometric constant (kPa °C^{-1}). This method is however not applicable for quantifying crop evapotranspiration (ET_c) of plant grown in greenhouse, so some researcher had indicated that they used machine learning model for ET prediction (Ge et al., 2022).

Reference evapotranspiration (ET_o) is sometimes interchanged to reference crop evapotranspiration and it is the rate of water evaporated from hypothetical references crop with an assumed crop height of 0.12 m, the surface resistance of 70 sec $m^{-1,}$ and an albedo of 0.23 closely matching evapotranspiration rate from dense green-grass of uniform height, vigorously growing, well irrigated, and completely shading the entire soil surface. The reference crop is not exposed to water stress and is free of diseases (Irmak and Haman, 2003). In the experiments, the researchers use grass and alfalfa crops as references, as the two crops entirely cover the ground surface. In this study, we quantified ETo using climate parameters, including minimum and maximum temperature, relative humidity, wind speed, daily sunlight duration, and solar radiation.

To compute the crop evapotranspiration, the crop coefficient (Kc) obtained from the FAO crop coefficient data and ETo was used. ET_o is an input parameter used to quantify crop evapotranspiration when the coefficient of crops (K_c) in different stages is known (Equation 2).

$$ETc = ET\mathrm{o} \times Kc \quad (2)$$

Where ETc is crop evapotranspiration and K_c is coefficient crop evapotranspiration.

2.4. The Crop Coefficient (Kc)

Crop Coefficient (Kc) is the ratio of ET_c to ET_o, which integrates the effect of characteristics that distinguish a specific crop’s water use from reference evapotranspiration. K_c is used to calculate ET_c. and sometimes use to partition ET_c into soil evaporation and plant transpiration. Kc is affected by crop varieties, growth stages, and climate and soil characteristics (Kang et al., 2003). CROPWAT requires the Kc of the crop in different stages. The K_c of tomato was updated from the FAO CLIMWAT database. The crop water requirement is the amount of water applied to compensate for the water lost through evapotranspiration and that from cropped fields (Ewaid et al., 2019)

3. Results and Discussion

3.1. Reference Evapotranspiration (ETo), Rainfall, and Effective Rainfall

The average daily ET_o throughout the year and the amount of rainfall and effective rainfall is given in Table 1, annual daily ET_o was calculated as 5.2 mm/day with a total of 1927.6 mm, the total rainfall is 584 mm and the total amount of effective rainfall is 511.4 mm. The highest ETo rates, range from 6.47, 6.28, and 6.04 mm in March, February, and January, respectively; both actual crop evapotranspiration and reference evapotranspiration were high due to higher temperature and lower relative humidity. Furthermore, the rainfall is low and ranges from 2 to 10 mm from January to March. The highest average rainfall changes from 62, 121, and 39 mm from October to December and 91, 94, and 64 mm from April to June accordingly and usually occurs during ‘Deyir’ (autumn) and ‘Gu’ (spring) seasons and that is why the rainfall in Somalia characterized by bio-model (figure 1). In Somalia, rainfall is the only climatic parameter that indicates seasonal weather changes (Muchiri, 2007). Wind speed, which is also high in dry seasons, contributes to an increase in the ETo rate. There is not enough literature focused on evapotranspiration except for evapotranspiration, which is available in the Global FAO Database, the FAO data contains the average monthly Potential Evapotranspiration (PET). According to the FAO Global database, the highest PET in Afgoye was recorded as 184.3 mm in March and the lowest PET was determined as 118.5 mm in June (Basnyat 2007; Muchiri, 2007).

As Figure 2 illustrates, rainfall and effective rainfall are not significantly different, and both are approximately equal at the ‘Jilaal’ (December to March) and ‘Xagaa’ (Jun to September) seasons and also indicate the bimodality of the rainfall i.e higher in rainy. FAO and SWALIM have also reported rainfall bimodality (Muchuri, 2007).

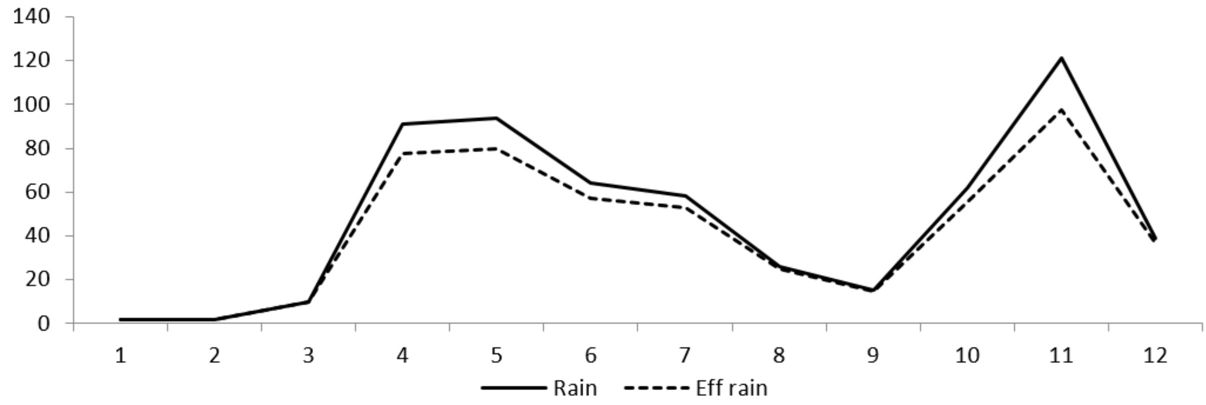

Figure 2. The rainfall and effective rainfall (mm).

Table 1. Minimum and Maximum temperatures, relative humidity (%), wind speed (km/h), sun (Hours), Rad (MJ/m²/day), rainfall, and effective rainfall

Month	Min Temp (°C)	Max Temp (°C)	Humidity (%)	Wind (km/day)	Sun (hours)	Rad (MJ/m²/day)	ET_o (mm/day)	Rainfall (mm)	Effective rainfall (mm)
January	21.6	33.5	65	346	7.9	20.6	6.04	2	2
February	21.8	34.1	70	363	9.2	23.5	6.28	2	2
March	23	35	69	328	9	23.6	6.47	10	9.8
April	23.5	34.3	71	216	7.5	20.8	5.37	91	77.8
May	23.1	32.8	76	216	6.4	18.3	4.61	94	79.9
June	22.6	31.2	79	259	6.2	17.3	4.22	64	57.4
July	21.5	30.5	75	259	7.9	20.1	4.71	58	52.6
August	21.5	31.1	75	268	8.1	21.2	4.95	26	24.9
September	21.7	32	71	268	8.5	22.5	5.5	15	14.6
October	22	32.2	72	242	7.5	20.8	5.18	62	55.8
November	21.8	32.3	67	181	6.8	19	4.78	121	97.6
December	21.6	33	66	277	6.6	18.4	5.32	39	36.6
Total								584	511.1
Average	22.1	32.7	71	269	7.6	20.5	5.29		

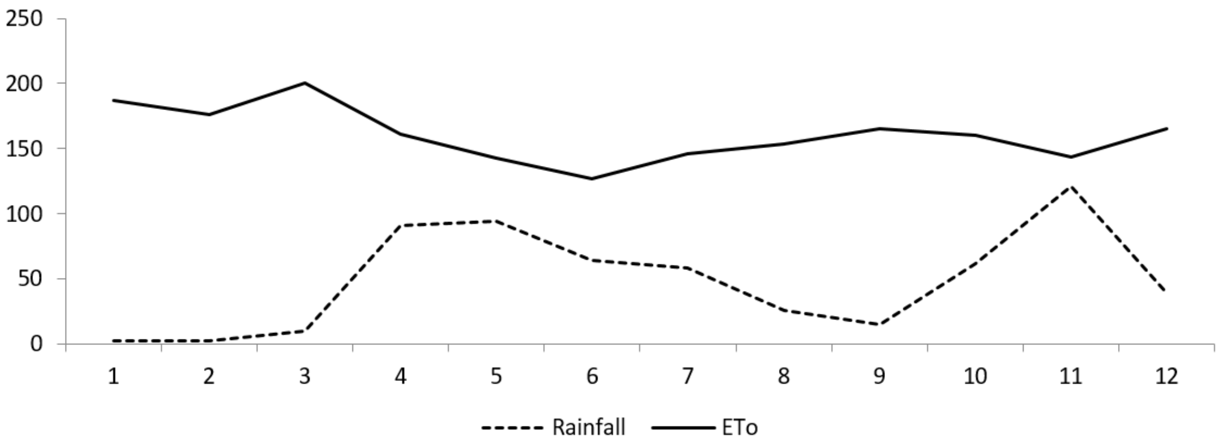

Figure 3. Rainfall and ETo (mm).

Figure 3 illustrates that rainfall cannot provide the amount of water required by reference crops i.e. hypothetical green grass or/ and alfalfa plant, the rainfall cannot cover the water requirement of a certain crop to meet its potential evapotranspiration.

3.2. Crop Coefficient, Irrigation, and Crop Water Requirement

Table 2 presents the crop and irrigation water requirements, crop coefficients, and effective rainfall values. At the initial stages, the daily average of tomato water use (ETc) was estimated to be very low, at 2.73, 2.83, and 2.88 mm/day. However, during the development stage, the tomato ETc ranged from 2.93 to 5.26 mm/day, indicating a rapid increase in crop evapotranspiration with the growth of the crop." In the middle stage, the crop water slightly increases from 6.05 to 6.19 mm/day; nevertheless, the tomato ET_c starts to decrease in this stage reaching 5.29 mm, In the final stage, the tomato ET_c experienced a rapid reduction reaching 4.01 mm, which was attributed to senescence and fall of tomato leaves. The crop coefficient of tomato, which is used for quantifying tomato crop water use, is also low at the initial stage and starts to promptly increase at the development and middle stages. At the initial stage, the lowest and highest tomato Kc was 0.6 and 1.15 in the middle stage, and Kc increased with the growth of the crop. Furthermore, the CROPWATT model also provides ET_c in every 10 days.

During the growing period of the crop, as can be seen in Table 2. The average ET_c in mm per decade also matches the one estimated as mm per day, illustrating that it increases with the development of crop stages. During the entire growing period, the total tomato ET_c was estimated as 678.2 mm which is higher than the aforementioned total annual rainfall. The model calculates rain and irrigation water required in decade per millimeter during the growing period, the lowest irrigation is 2.7 mm in the first ten days after planting and rapidly increases reaching 59 mm in the middle stage, and the irrigation decreases in the final stages. The tomato plant growing Afgoye from summer to autumn requires 451.3 an irrigation amount which is supplemented by 230.6 mm of effective rainwater that falls during this period, indicating that the irrigation amount is also lower than ET_c (Figure 4 and Table 3). However, the amount of water loses through ET_c is slightly lower than the total amount of irrigation and rainwater, indicating that the largest portion of water applied to plants as irrigation and rainwater is lost through evapotranspiration. Therefore, some plants that are not resistant to water stress cannot be grown in rainfed areas far from the river.

In Kenya, Maing et al. (2020) reported that the total tomato crop evapotranspiration reached 437.2 mm/dec, which lower than the amount found in this study. However, the growing period and the climate characteristics of their study area differ from this study area (Afgoye). On the other hand, the study area mentioned by the cited researchers receives more rainfall, indicating that the irrigation amount needed to supplement the rainfall is significantly lower comparing to Afgoye where the irrigation amount required is higher than the total amount the effective rains. At Kabete in Kenya Karuku et al. (2014) stated that tomato water requirement in this area reaches 456.5 mm/dec. In some area in Ethiopia, high tomato water requirement was reported (Desta et al., 2017).

The total mean of gross irrigation is estimated as 561.3 mm, while the total mean net irrigation reaches roughly 393.0 mm, demonstrating that irrigation efficiency reaches 70%. Net irrigation (NIR) is the quantity of water required by the crop to meet its evapotranspiration or the quantity of water applied as irrigation to reach field capacity, while gross irrigation is the total amount of water applied to cropping fields. Net irrigation is governed by climatic characteristics, soil types, and cropping patterns (Ewaid et al., 2019). Traditional irrigation practices are mainly used in Somalia, particularly Afgooye and other riverine farming, and river water conveyed by a canal distanced from the river encourages the loss of a significant amount of water through both evaporation and evapotranspiration.

Table 2. Tomato crop water requirement (initial, development, middle, and later stages)

Month	Decade	Stage	K_c	ET_c (mm/day)	ET_c (mm/dec)	Eff rain (mm/dec)	Irr. Req. (mm/dec)
Jul	1	Init	0.6	2.73	2.7	1.9	2.7
Jul	2	Init	0.6	2.83	28.3	18.6	9.7
Jul	3	Init	0.6	2.88	31.6	15.2	16.5
Aug	1	Deve	0.6	2.94	29.4	10.9	18.6
Aug	2	Deve	0.7	3.48	34.8	7.5	27.3
Aug	3	Deve	0.85	4.35	47.8	6.6	41.2
Sep	1	Deve	0.99	5.26	52.6	4.4	48.2
Sep	2	Mid	1.12	6.15	61.5	2.5	59
Sep	3	Mid	1.15	6.19	61.9	7.9	54
Oct	1	Mid	1.15	6.06	60.6	14	46.6
Oct	2	Mid	1.15	5.94	59.4	18.6	40.8
Oct	3	Mid	1.15	5.79	63.6	23.3	40.4
Nov	1	Late	1.09	5.29	52.9	31.1	21.8
Nov	2	Late	0.97	4.54	45.4	37.4	8
Nov	3	Late	0.85	4.15	41.5	29	12.5
Dec	1	Late	0.78	4.01	4	1.8	4
					678.2	230.6	451.3

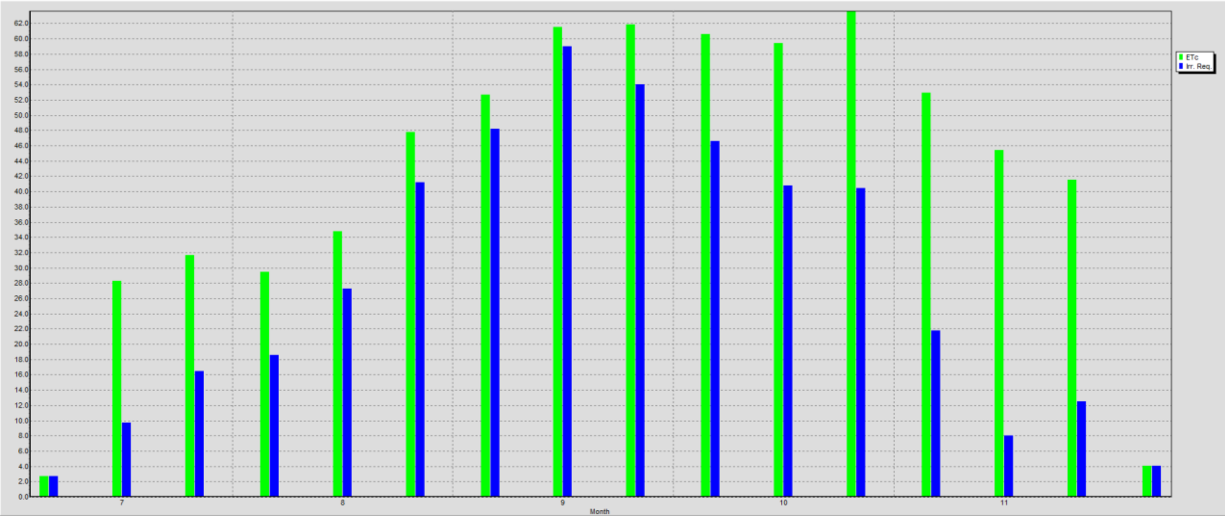

Figure 4. ETc and Irrigation requirement.

Table 3. Irrigation schedule

Date	Day	Stage	Rain (mm)	Ks	Depl (%)	Net Irr (mm)	Deficit (mm)	Loss (mm)	Gr. Irr (mm)	Flow (l/s/ha)
1-Aug	23	Init	0	1	31	30.4	0	0	43.4	0.22
21-Aug	43	Dev	0	1	35	49.2	0	0	70.3	0.41
6-Sep	59	Dev	0	1	37	66	0	0	94.3	0.68
20-Sep	73	Mid	0	1	40	80.3	0	0	114.7	0.95
6-Oct	89	Mid	0	1	41	82.3	0	0	117.5	0.85
26-Oct	109	Mid	0	1	42	84.8	0	0	121.2	0.7
1-Dec	End	End	0	1	24					
						392.9			561.3 mm	

Using an advanced irrigation systems and exposing the tomato to deficit irrigation can however, increase water use efficiency, as well as crop such soluble solids (Lu et al., 2019). Therefore, it is necessary to use appropriate irrigation practices to increase the efficiency of irrigation water fruit qualities.

4. Conclusion

CROPWAT 8.0 is employed to quantify ET_o, effective rainfall, crop water requirement (ET_c), and irrigation water demand of tomatoes. Climate, soil, and crop data were obtained from the FAO CLIMATWAT 2.0. Irrigation demand of tomato through its whole growing period was estimated as 451.3 mm and the effective rainfall to supplement the tomato crop water requirement was determined as 230.6 mm and the total tomato evapotranspiration reached 678.2 mm, the net and gross irrigation were estimated at 392.9 and 561.3 mm respectively. The results were not obtained from field experiments but were estimated using computer software and secondary data. Therefore, it is necessary to conduct an experimental study to validate or evaluate the accuracy of these findings and/or whether the model overestimates crop water requirements.

Afgoye is an agriculture zone characterized by a semi-arid climate; the irrigation crop water requirement is high, and sometimes there is not enough rainfall and river flow which can support the growth of many staple crops, therefore, it is required to conduct experimental studies to validate the CROPWAT model and determine an effective irrigation technique which improves water use efficiency with optimal crop production.

Author Contributions

The percentage of the author contributions is presented below. The author reviewed and approved the final version of the manuscript.

	Y.M.I.
C	100
D	100
S	100
DCP	100
DAI	100
L	100
W	100
CR	100
SR	100
PM	100
FA	100

C=Concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The author declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because of there was no study on animals or humans.

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