Journal of Biology, Agriculture and Healthcare
ISSN 2224-3208 (Paper) ISSN 2225-093X (Online)
Vol.11, No.8, 2021

Estimation of Crop Water Requirement Using CROPWAT Model for Onion and Tomato, A Case Study of Raya Azebo District, Ethiopia

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Abstract
Water is becoming gradually scarce worldwide. Aridity and drought are considered natural causes of scarcity of water on earth. Man-made desertification and water shortages have further aggravated the natural scarcity of water worldwide. Water scarcity has a huge impact on food production and without water people do not have a means of watering their crops and therefore, to provide food for the fast-growing population, farmers need to increase their output from existing cultivated areas to satisfy the food demand of an increasing population in the world especially in Ethiopia. Irrigation systems essential to enhance crop productivity in order to meet future food demand and ensure food security. The study was carried out to estimate the crop water requirement of onion and tomato in Raya valley, Northern Ethiopia. By using the climatic data, cropevapotranspiration (ETc)and reference crop evapotranspiration (ETo) for each crop were determined using CROPWAT 8.0.The study shows that crop water requirement of onion with a growing period of 100 days to maturity requires 366.0 mm depth of water on off season and 338.9 mm on main season respectively. Crop water requirement of tomato with a growing period of 125 days to maturity requires 509.9 mm depth of water on off season and 472.1 mm on main season respectively. These results can be used for planning and for most efficient water use and to optimize production of the onion and tomato in the study district.
Keywords: Reference Evapotranspiration (ETo), Crop water requirement (ETc), Model, Onion, Tomato,CROPWAT
DOI: 10.7176/JBAH/11-8-04
Publication date: April 30th 2021

1. Introduction
Water is the basic requirement for agricultural and the economic development of any country.Water is becoming valuable and scarce due to its increasing demand in agriculture and industrial sector.Agriculture being the backbone of population and exploitation of available water resources to meet the agricultural need requires its scientific management.

The values for crop evapotranspiration and crop water requirement are therefore, identical (except opposite sign), crop waterrequirement refers to the amount of water that needs to be supplied(positive sign), while crop evapotranspiration refers to the amountof water that is lost through evapotranspiration (negative sign).

CROPWAT facilitate the estimation of crop evapotranspiration, irrigation schedule and agricultural water requirements with different cropping patterns for irrigation planning and management. Penman-Monteith method (Allen et al. 1998) has been reported to yield consistently more accurate reference evapotranspiration (ETo) estimates across a wide range of climate condition (Jensen et al. 1990; Kashyap and Panda 2001; Irmak et al. 2003).

Different crops have different water use requirements under the same weather condition. Estimation of crop water requirements (ETc) is one of the main components used in irrigation planning, design and operation (Rowshon et al., 2013). (Jensen et al. 1990), provided detailed reviews of the methods commonly used to determine evapotranspiration and estimated crop water requirements.

In actual fact, CROPWAT is a computer program for irrigationplanning and management, developed by FAO (Abdalla et al. 2010). However, the sameprinciple holds for rain-fed crop production as well. Its basic functionincludes the calculation of reference crop evapotranspiration, cropwater requirement and scheme irrigation requirement. Althoughseveral methods exist to determine ETo, the Penman Monteith methodhas been recommended as the appropriate combination method todetermine ETo from climatic data on: temperature, humidity, sunshineand wind speed are required (Allen et al. 1998).

The crop water requirement (ETc) was found to vary not only with the crops its stage and duration, but also with the season as well. The crops differed in water demand as the growing season changed. During initial stage of the crops, the ETc was less and increased during development stage, reached to its maximum values during mid-season and reduced during crop maturation stages. ETc was maximum for winter season and lowest in summer season. The information generated can be used in scheduling irrigation for different crops.

The FAO-Penman-Montieth equation is recommended as the standard method for estimating reference and crop evapotranspiration as well as crop irrigation water requirement through the FAO CROPWAT model.

CROPWAT is one of the models extensively used in the field of water management throughout the world. CROPWAT facilitate the estimation of crop evapotranspiration, irrigation schedule and agricultural water requirements with different cropping patterns for irrigation planning and management. Different crops have different water use requirements under the same weather condition. The study was conducted with the objectives of Estimating Crop Water Requirement using CROPWAT model for most market-oriented crops under different cropping calendars.

2. Methodology

2.1. Description of the study area

Tigray is located in the northern part of Ethiopia with an altitude ranging between 400 to almost 4,000 m above mean sea level. It is located between 12° 15' N and 14° 57' N, and 36° 27' E and 39° 59' E. It covers an area of about 53,000 km² (CSA, 2015). The study was conducted in Raya Azebo district, SouthernZone of Tigray, Ethiopia.Administratively, Raya Azebo is subdivided into 18 kebeles at an altitude ranging from 930 to 2,300 m above mean sea level (Tesfay et al., 2014). The climate is predominantly semi-arid with irregular rainfall accompanied by frequent drought periods.Average annual rainfall ranges from 800 to 1,000 mm per year reducing to 400 mm (Edwards et al., 2006).

2.2. Crop water requirements

The reference evapotranspirationETo of individual agro-ecological units are calculated by FAO PenmanMonteith method, using decision support software –CROPWAT 8.0 developed by FAO, based on FAO Irrigation and Drainage Paper 56 (FAO 1998). The FAO CROPWAT program (FAO, 2009) incorporates procedures for reference crop evapotranspiration and crop water requirements and allow the simulation of crop water use under various climate, crop and soil conditions (www.fao.org).

2.3. CROPWAT 8.0

CROPWAT 8.0 has been developed by Joss Swennenhuis for the Water Resources,Development and ManagementService of FAO. CROPWAT 8.0 is based on the DOS versions CROPWAT 5.7 of 1992 and CROPWAT 7.0 of1999 The most common version now is CROPWAT 8.0 Edition (2009), which was developed under the assistancefrom the university of Southmpton and Institute of Irrigation and Development studies. CROPWAT is a computer program which uses the FAO Penman-Monteith procedure for the estimation of reference crop evapotranspiration(Eto), crop evapotranspiration (Etc) and irrigation scheduling (FAO 1998). Major input parameters of the program areMeteorological data, crop growth data & soil data.

3. Results and Discussion

3.1. Reference evapotranspiration (Eto)

The following table (1) gives the Reference Evapotranspiration (Eto) for all the months in a year, in which the highestreference evapotranspiration is found in the month June (4.7 mm/ day) and the lowest Reference evapotranspiration isfound in the month January (3.3 mm/ day) and November (3.77 mm/ day) due to differential changes occurs in theweather conditions like temperature, sunshine hours, humidity and wind speed.

In dry season, the resulting low relative humidity combined with high temperatures led to increased evapotranspiration over this period of a year. Inversely the low values of Eto in rainy season may be due to the high frequencies of rainfall combined with high relative humidity and relative low temperatures. As the trend of Eto affecting by climatic factors such as temperatures, solar radiation, and rainfall as well as wind, relative humidity of the air consequently Eto is a climatic parameter. With the variations of these parameters Eto were vary greatly within and between seasons. The results are in accordance with Adeniran et al. (Adeniran et al., 2010), which showed that Eto was lowest during the peak of the rainy season to highest during the peak of the dry season.

Table 1.Long term monthly average climatic data of the experimental area

Month	T_{min} °C	T_{max} °C	RH %	Wind km/hr	Sun hours	Rad MJ/m²/day	Eto mm/day
January	11.5	27.2	73	69	7.9	18.4	3.33
February	12.8	27.1	70	86	9.4	22.0	4.02
March	13.5	29.5	68	86	8.7	22.4	4.44
April	13.8	29.7	67	95	8.7	22.9	4.65
May	15.3	32.5	58	52	9.1	23.3	4.69
June	15.8	35.0	60	43	8.6	22.2	4.70
July	15.6	31.5	90	52	6.5	19.1	4.04
August	15.0	29.7	95	43	6.5	19.3	3.89
September	14.3	30.8	74	52	6.6	19.2	3.96
October	13.1	29.8	69	86	9.2	22.0	4.36
November	12.1	28.6	67	69	9.0	20.1	3.77
December	11.3	27.1	69	69	8.8	19.0	3.4

3.2. Crop Water Requirement, Effective rainfall and Irrigation Requirement

From the below results (Table 2), It shows that for onion in off season and main season, it requires 366.0 and 338.9mm crop water requirement, 42.7and 97.6mm effective rain fall and 323.3and 241.3mm irrigation requirement respectively. For tomato in off season and main season, it requires 509.9 and 472.1mm crop water requirement, 60.3 and 122.1mm effective rain fall and 449.6 and350.0mm irrigation requirement respectively. It shows that in off season the crop water requirement of onion and tomato were needed more water than the main season, due to the climatic condition and in the main season the effective rainfall is more available than the off season.

Table 2.Crop water Requirement, Effective Rainfall, Irrigation Requirement.

Season	Crops	Crop Water Requirement (mm)	Effective rainfall (mm)	Irrigation Requirement (mm)
Off season	Onion	**366.0**	42.7	323.3
	Tomato	**509.9**	60.3	449.6
Main season	Onion	**338.9**	97.6	241.3
	Tomato	**472.1**	122.1	350.0

Table 3.Crop water requirement for onion on off season

Month	Decade	Stages	Kc Coef	ETc (mm/day)	ETc (mm/dec)	Eff rain (mm/dec)	Irr. Req (mm/dec)
Jan	2	Init	0.50	1.67	10.0	0.0	10
Jan	3	Init	0.50	1.79	19.6	6.0	13.6
Feb	1	Deve	0.56	2.13	21.3	0.0	21.3
Feb	2	Deve	0.77	3.11	31.1	4.6	26.5
Feb	3	Deve	0.97	4.03	32.2	8.4	23.8
Mar	1	Mid	1.04	4.49	44.9	0.0	44.9
Mar	2	Mid	1.04	4.64	46.4	7.8	38.6
Mar	3	Mid	1.04	4.71	51.8	0.0	51.8
Apr	1	End	1.03	4.71	47.1	10.2	36.9
Apr	2	End	0.96	4.46	44.6	0.0	44.6
Apr	3	End	0.91	4.23	16.9	5.7	11.2
Total					**366.0**	**42.7**	**323.3**

Table 4.Crop water requirement for onion on main season

Month	Decade	Stages	Kc Coef	ETc (mm/day)	ETc (mm/dec)	Eff rain (mm/dec)	Irr. Req (mm/dec)
Jun	2	Init	0.50	2.35	14.1	0.0	14.1
Jun	3	Init	0.50	2.24	22.4	0.0	22.4
Jul	1	Deve	0.54	2.31	23.1	10.9	12.2
Jul	2	Deve	0.74	2.99	29.9	16.8	13.1
Jul	3	Mid	0.96	3.81	41.9	11.7	30.2
Aug	1	Mid	1.02	4.03	40.3	10.0	30.3
Aug	2	Mid	1.02	3.98	39.8	12.8	27
Aug	3	Mid	1.02	4.00	44.0	15.1	28.9
Sep	1	End	1.00	3.93	39.3	14.6	24.7
Sep	2	End	0.93	3.68	36.8	0.0	36.8
Sep	3	End	0.89	3.64	7.3	5.7	1.6
Total					**338.9**	**97.6**	**241.3**

Table 5.Crop water requirement for tomato on off season

Month	Decade	Stages	Kc Coef	ETc (mm/day)	ETc (mm/dec)	Eff rain (mm/dec)	Irr. Req (mm/dec)
Jan	2	Init	0.60	2.01	12.1	0.0	12.1
Jan	3	Init	0.60	2.14	23.6	6.0	17.6
Feb	1	Deve	0.60	2.30	23	0.0	23
Feb	2	Deve	0.72	2.89	28.9	4.6	24.3
Feb	3	Deve	0.86	3.57	28.6	8.4	20.2
Mar	1	Deve	1.00	4.29	42.9	0.0	42.9
Mar	2	Mid	1.13	5.02	50.2	7.8	42.4
Mar	3	Mid	1.14	5.17	56.9	0.0	56.9
Apr	1	Mid	1.14	5.25	52.5	10.2	42.3
Apr	2	Mid	1.14	5.33	53.3	0.0	53.3
Apr	3	End	1.14	5.34	53.4	5.7	47.7
May	1	End	1.03	4.82	48.2	8.0	40.2
May	2	End	0.86	4.04	36.3	9.6	26.7
Total					**509.9**	**60.3**	**449.6**

Table 6.Crop water requirement for tomato on main season

Month	Decade	Stages	Kc Coef	ETc (mm/day)	ETc (mm/dec)	Eff rain (mm/dec)	Irr. Req (mm/dec)
Jun	2	Init	0.60	2.82	16.9	0.0	16.9
Jun	3	Init	0.60	2.69	26.9	0.0	26.9
July	1	Deve	0.60	2.56	25.6	10.9	14.7
Jul	2	Deve	0.70	2.82	28.2	16.8	11.4
Jul	3	Deve	0.86	3.42	37.7	11.7	26
Aug	1	Deve	1.02	4.01	40.1	10.0	30.1
Aug	2	Mid	1.13	4.38	43.8	12.8	31
Aug	3	Mid	1.13	4.43	48.7	15.1	33.6
Sep	1	Mid	1.13	4.45	44.5	14.6	29.9
Sep	2	Mid	1.13	4.48	44.8	0.0	44.8
Sep	3	End	1.12	4.59	45.9	5.7	40.2
Oct	1	End	0.99	4.25	42.5	12.6	29.9
Oct	2	End	0.85	3.78	26.5	11.9	14.6
Total					**472.1**	**122.1**	**350**

3.3. Average monthly maximum, minimum temperature and reference evapotranspiration (ETo)

From the below figure, the Reference Evapotranspiration (ETo) for all the months in a year, in which the highestreference evapotranspiration is found in the month June (4.7mm/ day) and the lowest Reference evapotranspiration isfound in the month January (3.3mm/ day). This result was showed that the crop water requirement in those months require higher amount of water.

The maximum temperature was recorded in the month of June followed by may with the value of 35.5 and

32.5^0c. In the other hand the minimum temperature wasshowed that in the month of December, January and November respectively.

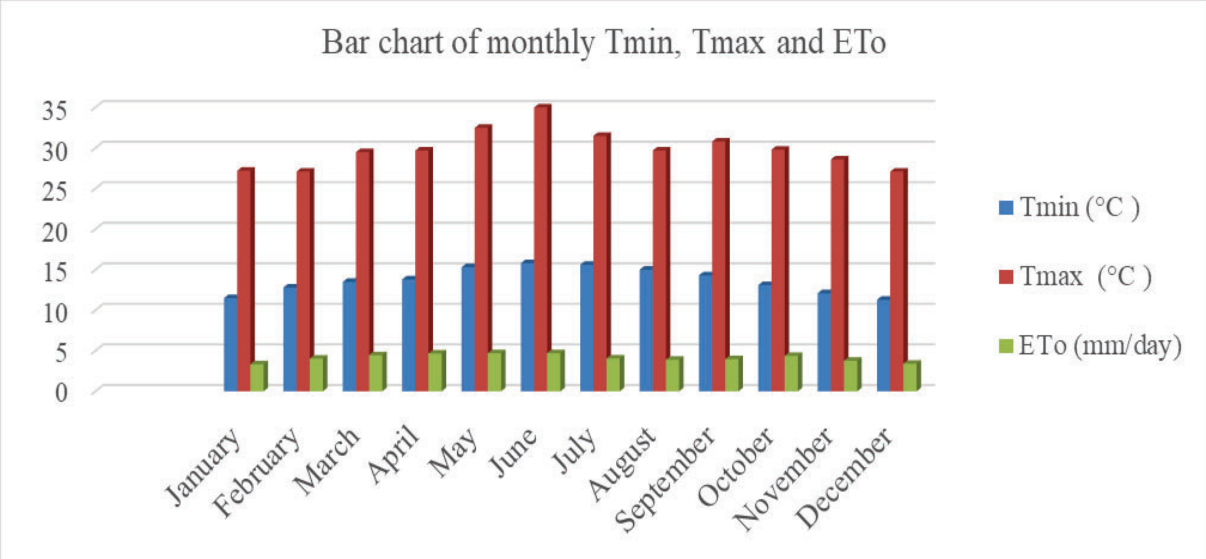

Figure1: Bar Chart indicating long term average monthly minimum, maximum and reference crop evapotranspirationdata of the district

3.4. Crop Water Requirement, Effective Rainfall and Irrigation Requirement of onion and tomato

From the below bar graph, onion and tomato were required higher crop water requirement in the off season than in the main season. This reason, due to maximum temperature, higher sunshine hour, high wind speed and reference evapotranspiration (ETo).

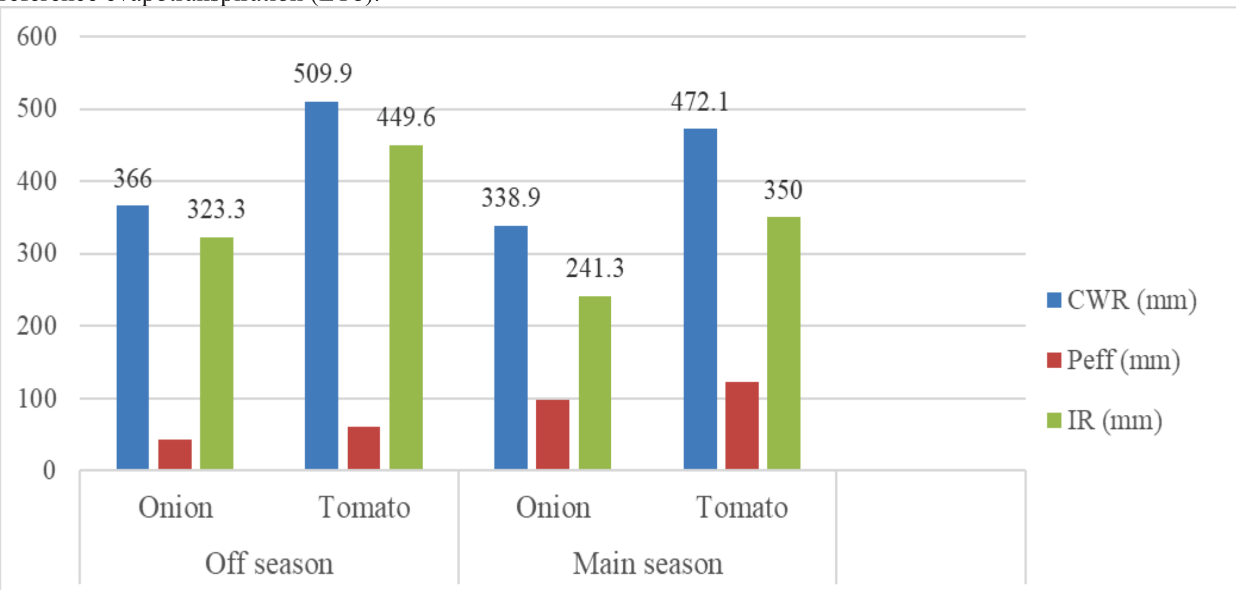

Figure 2: Bar Chart Indicating the Crop Water Requirement, Effective Rainfall and Irrigation Requirement of onion and tomato

4. Conclusion

Crop water requirement of onion with a growing period of 100 days to maturity requires 366.0 mm depth of water on off season and 338.9mm on main season respectively. Crop water requirement of tomato with a growing period of 125 days to maturity requires 509.9 mm depth of water on off season and 472.1mm on main season respectively.From the present study, it is concluded that Reference Crop Evapotranspiration, Effective Rainfall, Crop water requirement and Irrigation water requirement can be estimated using CROPWAT 8.0 Software with the input of climatic data like maximum and minimum temperature, relative humidity, wind speed and sunshine hours and rainfall.It showed the significance of requirement of scientific planning for irrigation. Results on ETc and IR provided practical assessment for irrigation scheduling of onion and tomato grown in these t semi-arid environments. These results can be used for a most efficient water use and to optimize production of the onion and tomato in the study district.

Acknowledgements
The authors wish to express their appreciation toEthiopian Institute of Agricultural Research (EIAR) forfunding this research project and financial support. Theauthors also truthfully appreciate Mekhoni AgriculturalResearch Center (MehARC) for given that all necessarysupport during the implementation of the model.

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