Estimation of Crop Water Requirement of *Kharif* Maize Crop Using CROPWAT 8.0 Model in Bilaspur District

ABSTRACT

Water is one of the most important elements in this world. No life will exist without water. The main consumer of water is agriculture but due to mismanagement, overpopulation, and climatic changes this valuable natural resource is getting scarce position throughout the world. It has become very important to define appropriate strategies for planning, development, and management of water resources. The main objective of this paper is to the estimation of crop water requirement of *Kharif* maize crop for effective irrigation management. For proper irrigation management, CROPWAT is the best model suggested by FAO. 16-year climatic data were analyzed with the CROPWAT model, which is based on the United Nations Food and Agriculture Organization (FAO) paper number 56 (FAO 56). The Penman-Monteith method was used to estimate reference evapotranspiration (ET_0). The model predicted the daily, decadal as well as monthly crop water requirement at different growing stages of maize crop. The average reference crop evapotranspiration (ETc) during the 16 years was found to be 313.21 mm. It varies from 222.8 mm to 515.9 mm. The average irrigation requirement for maize crops during the period from 25th June to 17th September was 42.01 mm.

Keywords: Crop water requirement; Crop evapotranspiration; Reference evapotranspiration; Effective rainfall, CROPWAT.

INTRODUCTION

One of the most important natural resources is water, which is crucial for maintaining biodiversity, our health, social welfare, and economic growth (Donald, 1968). Water is the most critical input for agriculture and the demand for efficient use of irrigation water for crops is intensifying in view of changing climate. Irrigation water supplies are decreasing day by day and scarcity has been seen in many areas of the world. (Roja *et al.,* 2020)

The adoption of the exact or correct amount of water and correct timing of application is very essential for scheduling irrigations to meet the crop's water use demands and for optimum crop production. 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.

Maize (*Zea mays L.*) is another important *Kharif* crop in the state of Chhattisgarh. It belongs to the Poaceae family and is the third most important crop in India after rice and wheat. The maize crop is one of the world's important food crops, which supplies more than

5% of dietary energy. It is cultivated around the year, though more than 80% is grown in the rainy or *Kharif* season (July to October). Globally, maize is known as the “Queen of cereals” because of its highest genetic yield potential.

Farmers can ensure adequate water management by either maintaining or reducing water use on their farms without any negative impact on crop yields and profit (Enciso *et al.,* 2015). Sonit *et al.*, (2015) applied drip irrigation with IW: CWE – 1.2 to 1.4 in summer paddy and concluded that it is superior to flooding in relation to water use efficiency. Jangre *et al.,* (2022) The average crop water requirement of *kharif* rice during the 21 years were found to be 575.64 mm in the Raipur district. Crop water requirements (CWR) depend on climatic conditions, crop area and type, soil type, growing seasons, and crop production frequencies (FAO, 2009; George *et al.,* 2000). CROPWAT is one of the models that are being extensively used in the field of water management throughout the world which is designed by Smith (1991) of the Food Agricultural Organization (FAO).

MATERIALS AND METHODS

Study area

The study area is Bilaspur district, Chhattisgarh, India (Figure 1). The meteorological observatory is located in Bilaspur at 22^{o}05’N latitude and 82^{o}13’ longitude and 272 m altitude above mean sea level (MSL). Bilaspur has a hot and semi-humid climate characterized by extreme cold in winter and extremely hot in summer. Based on rainfall and temperature the year may be divided into three distinct seasons namely the rainy season (from June to October), winter season (mid-November to February), and summer season (from March to May). The rainfall of the region is around 1082 mm. The Bilaspur district receives rainfall mainly from the southwest monsoon.

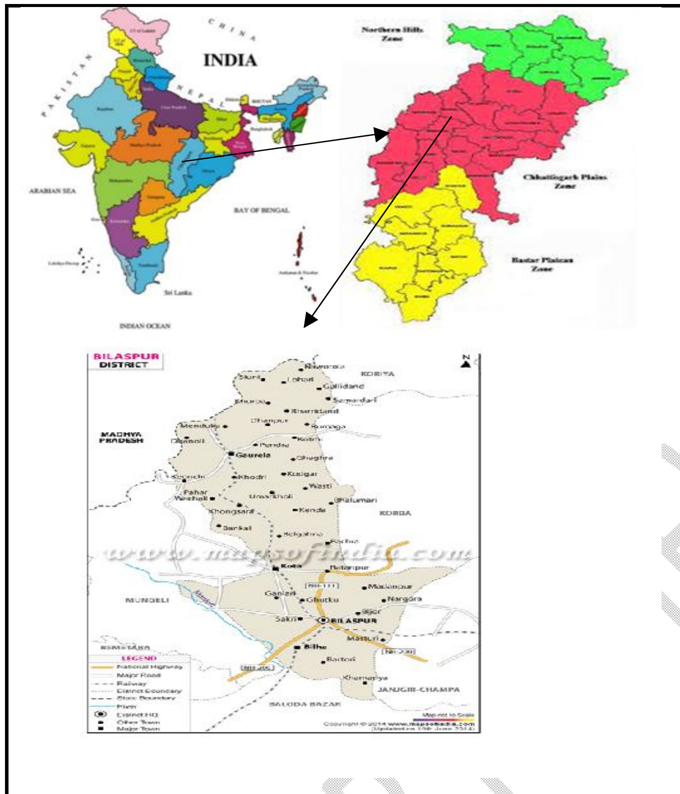


Fig.1.Map of the study area

Model description and input data

CROPWAT 8.0

CROPWAT 8.0 is a freeware software for the calculation of crop water requirements based on soil, climate, and crop data and existing or new irrigation climate data and crop needs (Doorenbos & Pruitt, 1976,1977). CROPWAT 8.0 can also be used to evaluate farmers' irrigation practices and to estimate crop performance under both rain-fed and irrigated conditions. All procedures of calculation in CROPWAT 8.0 are based on the two FAO publications of the Irrigation and Drainage Series, namely, No. 56 "Crop Evapotranspiration – Guidelines for computing crop water requirements" and No. 33 titled "Yield response to water". To execute a simulation of CROPWAT model, it is necessary to have sets of data: climate data, rain data, crop data, soil data, and irrigation criteria. Climatic condition determines evapotranspiration computed by the Penman-Monteith formula which is implemented in CROPWAT (Allen *et al.*, 1998)**.** The methodology adopted in the present research has been shown in Fig. 2 in the below flowchart:

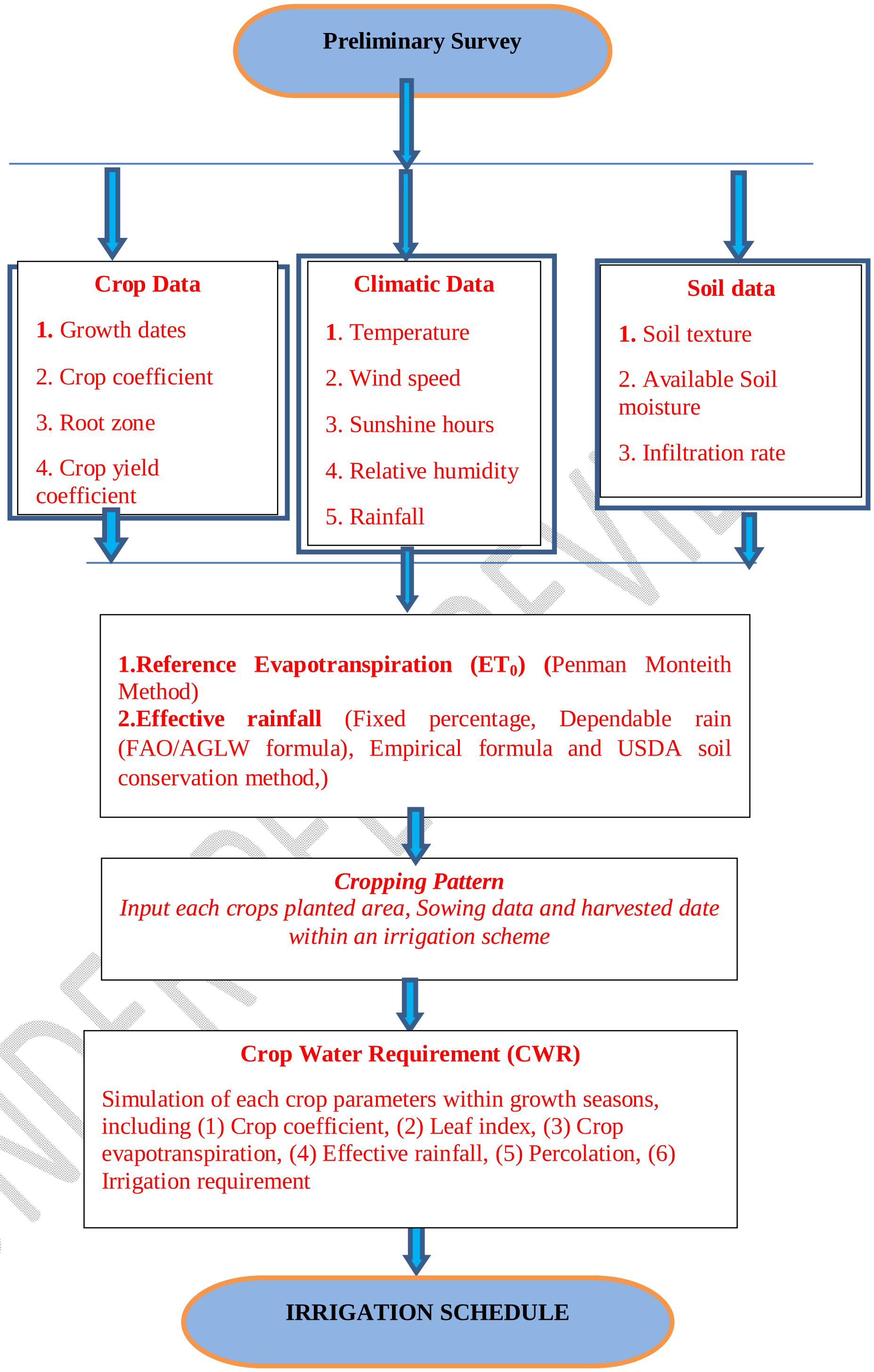


Fig. 2 Flowchart for estimation of crop water requirement in CROPWAT 8.0

Crop water requirement

The method used for determine the crop water requirement was done using the FAO CROPWAT model applying the procedures described by FAO Water. Data requirements for the model included: crop, soil, and climate data. Climatic values required include total monthly precipitation (P), potential evapotranspiration (PET), and average maximum and minimum temperature per month.

The crop water requirement is the amount of water equal to what is lost from a cropped field by the ET and is expressed by the rate of ET in mm/day. The estimation of CWR is derived from crop evapotranspiration (ET_c) which can be calculated by the following equation (1):

$$ET_c = K_c \times ET_0 \qquad \dots (1)$$

where K_c is the crop coefficient.

Reference Evapotranspiration (ET_0)

The reference evapotranspiration ET_0 was calculated by FAO Penman-Monteith method, using decision support software –CROPWAT 8.0 developed by FAO, based on FAO Irrigation and Drainage Paper 56 named FAO 56. The mathematical expression of the reference evapotranspiration is as follows: FAO Penman-Monteith Procedure the Crop Evapotranspiration (ET_c) is also estimated by FAO Penman-Monteith Equation (2):

$$ET_0 = \frac{0.408\,\Delta\,(R_n - G) + \gamma \frac{900}{(T+273)} u_2\,(e_s - e_a)}{\Delta + \gamma\,(1 + 0.34\,u_2)} \qquad \dots (2)$$

Where,

ET_0 = Reference evapotranspiration [mm day^{-1}]

R_n = Net radiation [MJ m^{-2} day^{-1}]

G = Soil heat flux density [MJ m^{-2} day^{-1}]

T = Mean daily air temperature at 2 m height [°C]

u_2 = Wind speed at 2 m height [m s^{-1}]

e_s = Saturation vapour pressure [kPa]

e_a = Actual vapour pressure [kPa]

$e_s - e_a$ = Saturation vapour pressure deficit [kPa]

Δ = Slope of the vapour pressure curve [kPa $°C^{-1}$]

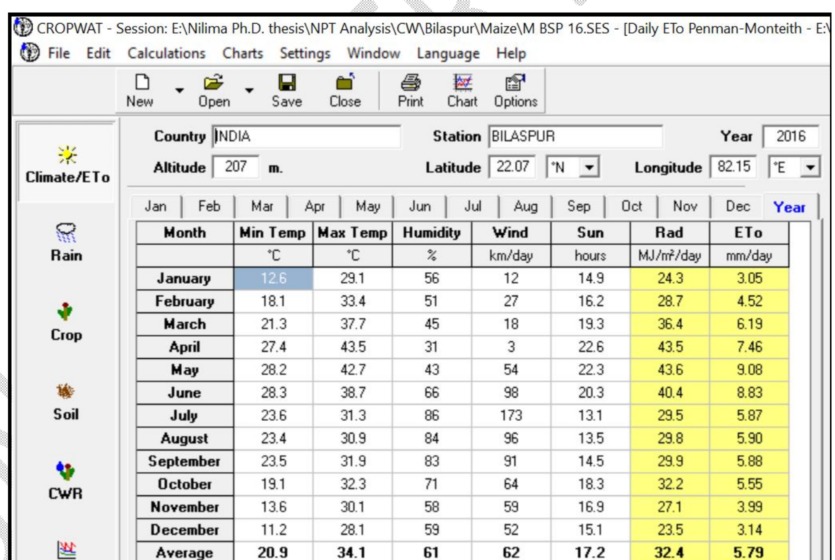
γ = Psychrometric constant [kPa $°C^{-1}$]

Meteorological data

Agro-meteorological data was collected from the meteorological observatory located in Bilaspur. The agro-meteorological data obtained from the Bilaspur station were converted into the required unit for ET_0 computation. The study is carried out by taking the minimum and maximum temperatures ($^{\circ}$C), wind speed in km per day, maximum and minimum relative humidity (%) and the maximum hours of sunshine, and the topographical data such as altitude, latitude, and longitude. The rainfall data were also obtained from the meteorological station. Rainfall records for 16 years (2003-2018) were collected to predict the probability of rainfall events in the upcoming days.

Input weather data for CROPWAT

The daily weather data for 16 years have been observed and arranged in the form of a matrix to be fed into the CROPWAT window. The screenshot of CROPWAT 8.0 climate input data is shown in Fig.3. Although several methods exist to determine ET_0, the Penman-Monteith Method has been recommended as the appropriate combination method to determine ET_0 from climatic data like temperature, humidity, sunshine hours, and wind speed.

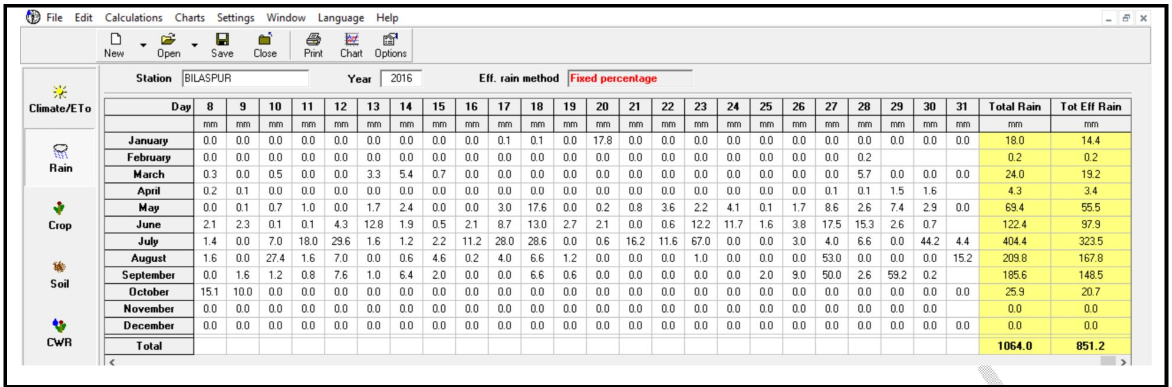


Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	12.6	29.1	56	12	14.9	24.3	3.05
February	18.1	33.4	51	27	16.2	28.7	4.52
March	21.3	37.7	45	18	19.3	36.4	6.19
April	27.4	43.5	31	3	22.6	43.5	7.46
May	28.2	42.7	43	54	22.3	43.6	9.08
June	28.3	38.7	66	98	20.3	40.4	8.83
July	23.6	31.3	86	173	13.1	29.5	5.87
August	23.4	30.9	84	96	13.5	29.8	5.90
September	23.5	31.9	83	91	14.5	29.9	5.88
October	19.1	32.3	71	64	18.3	32.2	5.55
November	13.6	30.1	58	59	16.9	27.1	3.99
December	11.2	28.1	59	52	15.1	23.5	3.14
Average	20.9	34.1	61	62	17.2	32.4	5.79

Fig.3. Climate input data file

Rain data:

Rain data was also collected from the Agrometeorological station Bilaspur and applied in CROPWAT software to obtain effective rainfall. A fixed percentage method has been adopted and effective rainfall has been considered as 80% of rainfall. Figure 4 shows a sample of rain data with effective rainfall obtained.



Day	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Total Rain	Tot Eff Rain
	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
January	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	17.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	18.0	14.4
February	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2				0.2	0.2
March	0.3	0.0	0.5	0.0	0.0	3.3	5.4	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.7	0.0	0.0	0.0	24.0	19.2
April	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	1.5	1.6		4.3	3.4
May	0.0	0.1	0.7	1.0	0.0	1.7	2.4	0.0	0.0	3.0	17.6	0.0	0.2	0.8	3.6	2.2	4.1	0.1	1.7	8.6	2.6	7.4	2.9	0.0	69.4	55.5
June	2.1	2.3	0.1	0.1	4.3	12.8	1.9	0.5	2.1	8.7	13.0	2.7	2.1	0.0	0.6	12.2	11.7	1.6	3.8	17.5	15.3	2.6	0.7		122.4	97.9
July	1.4	0.0	7.0	18.0	29.6	1.6	1.2	2.2	11.2	28.0	28.6	0.0	0.6	16.2	11.6	67.0	0.0	0.0	3.0	4.0	6.6	0.0	44.2	4.4	404.4	323.5
August	1.6	0.0	27.4	1.6	7.0	0.0	0.6	4.6	0.2	4.0	6.6	1.2	0.0	0.0	0.0	1.0	0.0	0.0	0.0	53.0	0.0	0.0	0.0	15.2	209.8	167.8
September	0.0	1.6	1.2	0.8	7.6	1.0	6.4	2.0	0.0	0.0	6.6	0.6	0.0	0.0	0.0	0.0	0.0	2.0	9.0	50.0	2.6	59.2	0.2		185.6	148.5
October	15.1	10.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.9	20.7
November	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	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	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total																									1064.0	851.2

Fig.4. Rain input data file

Crop data:

The software needs some information about the maize crop. That information had been obtained from FAO manual 56 for maize crop including crop name; planting date; harvest, crop coefficient, Kc; rooting depth length of plant growth stages; critical depletion and yield response factor. Values of K_c and rooting depth also are taken from the FAO manual, Figure 5 shows crop data applied in this software. In this study as per the local conditions of *Kharif* maize crop (Variety: JG-74: average rooting depth 45 cm). The average sowing date of 25th June and average harvesting date of 17th September having 85 days duration has been considered. As per the local conditions of *Kharif* maize grown in the study area four distinct stages have been found, namely; initial stage (15 days duration), development stage (20 days duration), mid-season stage (30 days duration), and late-season stage (20 days duration). The crop coefficient (K_c) values differ in various stages. In this study, the average value of K_c in different stages namely the initial stage, development stage, mid-season stage, and late-season stage the K_c value is taken as 0.70, 1.20, 1.20, and 0.6, respectively.

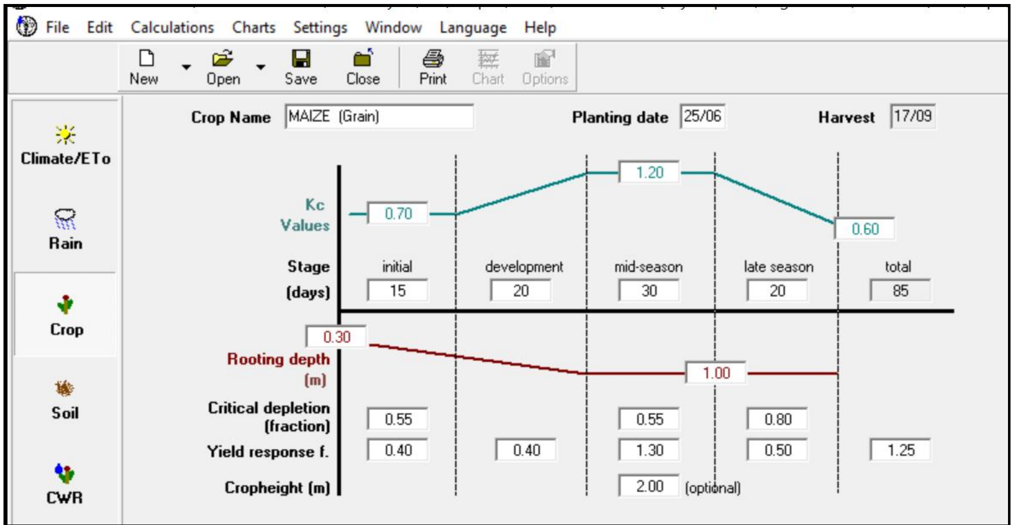


Fig.5. Crop input data file

Soil data

The data utilized on the soil characteristics were acquired through laboratory analysis. In the district, four types of soil are observed as per US soil taxonomy viz. Entisol, Inceptisol, Alfisol, and Vertisol. Inceptisol (Red sandy loam) soil is mostly covered in the Bilaspur district. The output of the analysis was entered into the CROPWAT 8.0 program and saved. Shown in Fig. 6

The Soil module is essential data input, requiring the following general soil data:

- Total Available Water (TAW)
- Maximum infiltration rate
- Maximum rooting depth
- Initial soil moisture depletion

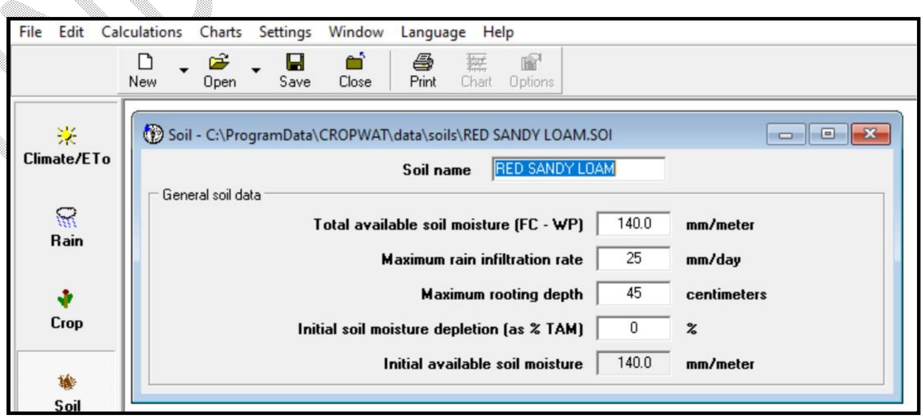
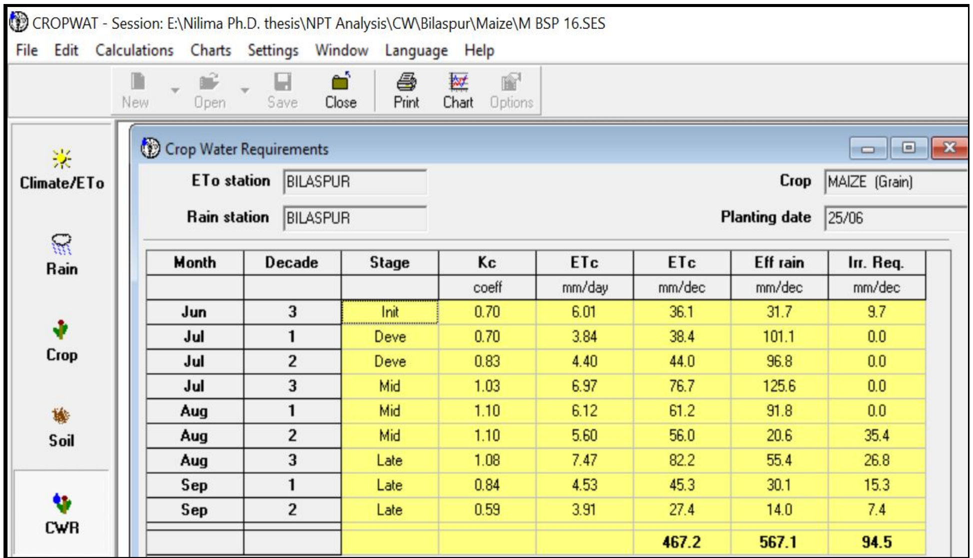


Fig.6. Soil input data file

Results and discussion

The crop water requirement of *Kharif* maize has been worked out for all 16 years (2003- 2018). The CROPWAT window for the year 2016 has been shown in Fig.7, the crop evapotranspiration is worked out to be 467.2 mm while the effective rainfall and irrigation requirement were worked out to be 567.1 mm and 94.5 mm, respectively. The crop evapotranspiration, effective rainfall, and irrigation requirement for all sixteen years have been computed and shown in Table 1 and Fig. 8 along with the average ET_c (**313.21** mm), average effective rainfall (**658.42** mm) and average irrigation requirement (**42.01** mm). The maximum ET_c (**515.9** mm) was observed in the year 2015 which also corresponds with the maximum irrigation requirement of **165.8** mm in the year 2014. It is to be noted that the maximum effective rainfall was observed in the year 2012 as **959.7** mm, which is associated with a minimum irrigation requirement of 0 mm. Also observed is that the effective rainfall is quite higher as compared to ET_c in all the years. This implies that *Kharif* maize crop can be taken with ease in the Bilaspur district. The average ET_c during the 16 years was found to be 313.21mm (S.D. 107.41 mm and C.V. 34.29%) while the average effective rainfall is about 658.42 mm (S.D. 148.74 mm and C.V. 22.59%), even there is average irrigation requirement of 42.01 mm (S.D. 45.23 mm and C.V. 107.66%). The results indicated that there was high variability in year-to-year variation in ET_c (34.29%). On contrary, the variability of effective rainfall was low (22.59%).

The analysis of data further reveals that the average reference evapotranspiration (ET_c) value is 313.21 mm. It varies from 222.8 mm to 515.9 mm and the average irrigation requirement is 42.01 mm. The crop water requirement (ET_c) for *Kharif* Maize was worked out to be 304 mm and irrigation requirements 288.2 mm, which is in conformity with the findings of Bhat, *et al.*, 2017. Similar findings were observed by Roja *et al.*, (2020) for the maize crop in north coastal districts of Andhra Pradesh in which the crop water requirement and irrigation requirement for maize crop was 238.6 mm and 212.6 mm.



Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Jun	3	Init	0.70	6.01	36.1	31.7	9.7
Jul	1	Deve	0.70	3.84	38.4	101.1	0.0
Jul	2	Deve	0.83	4.40	44.0	96.8	0.0
Jul	3	Mid	1.03	6.97	76.7	125.6	0.0
Aug	1	Mid	1.10	6.12	61.2	91.8	0.0
Aug	2	Mid	1.10	5.60	56.0	20.6	35.4
Aug	3	Late	1.08	7.47	82.2	55.4	26.8
Sep	1	Late	0.84	4.53	45.3	30.1	15.3
Sep	2	Late	0.59	3.91	27.4	14.0	7.4
					467.2	**567.1**	**94.5**

Fig.7. Output of crop water requirement of *Kharif* Maize for the year 2016 in Bilaspur district

Table 1:- Seasonal ET_c, effective rainfall, and irrigation requirement for *Kharif* Maize during the year 2003 to 2018 in Bilaspur district

Year	**ETc (mm)**	**Effective Rain (mm)**	**Irrigation Requirement (mm)**
2003	247.6	664.4	3.9
2004	260.9	485.3	33.4
2005	243.2	836.5	34.2
2006	288.6	682.6	11.9
2007	256.1	778.7	35.7
2008	264.4	557.6	11.9
2009	259.4	601.4	37.1
2010	257.5	733.1	0
2011	233.5	872.4	16.7
2012	261.8	**959.7**	7.6
2013	474.2	508.8	77.2
2014	506.2	740.7	**165.8**
2015	**515.9**	498.3	100.4
2016	467.2	567.1	94.5
2017	252.1	512.4	24.1
2018	222.8	535.7	17.8
Average	**313.21**	**658.42**	**42.01**
S.D.	**107.41**	**148.74**	**45.23**
CV	**34.29**	**22.59**	**107.66**

Fig.8. Crop evapotranspiration, Effective rain, and Irrigation Requirements for *Kharif* Maize in Bilaspur district

Conclusion

The study improves our understanding of the crop water requirements of *Kharif* maize crops in the Bilaspur district. The results indicate that the legitimate estimation of water requirements of maize crops will consequently help improve water resource management and productivity. Scientific tools like CROPWAT 8.0 can assess the CWR with a high level of accuracy. The assessment helps formulate the most appropriate cropping pattern and crop rotation that farmers can readily accept. The results of this study can be used by agriculturists and water resource planners for future planning, helping to conserve water while complying with CWRs, and can guide farmers in selecting the amount and frequency of crop irrigation.

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