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Study of Crop Evapotranspiration and Irrigation Scheduling of Different Crops Using Cropwat Model in Waghodia Region, India

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A B S T R A C T

To control the overexploitation of accessible water resources, it has become essential to define proper strategies for planning, development, and management of water resources. Proper modification in traditional irrigation practices helps improve water use efficiency. CROPWAT is an FAO suggested model for proper management of irrigation. CROPWAT model integrates with soil, crop, and climate information for estimation of reference evapotranspiration (ET_0), crop evapotranspiration (ET_c), crop water requirement (CWR) and irrigation water requirements (IWR).It also develops and manages the irrigation scheduling. The average annual rainfall of Waghodia region was 907mm of, and out of this, 527.6mm was useful for crop growth and development. The CWR for Waghodia Region is estimated as 241.3mm, 480.9mm, and 339.3mm and irrigation requirement as 188.8mm, 343.3mm, and 333.9mm for sorghum, rice, and wheat crop, respectively. CROPWAT 8.0 model can efficiently and effectively calculate the evapotranspiration and net requirements of irrigation water. The CROPWAT 8.0 Model can play an important role in the irrigation management practices as well as irrigation scheduling of crops over manual irrigation practicing using different water supply systems.

Introduction

The availability of freshwater water resources for agriculture is an alarming issue with increasing the demand of water for different sectors (IWMI, 2010). According to United Nations report (2019), the world population in 2050, will be predicted to peak at 9.7 billion. To attain the demand of the growing populace of the world, proper utilization of the available water resources is the main challenge for researchers. Among all freshwater using sectors around the world, agriculture contributes to an average of 70

percent (Alexandratos and Bruinsma, 2012). Since, water is highly used by agriculture, it is essential to improve agriculture water management practices and adopt some new water-saving measures for agriculture purposes. The principal reason for the irrigation is to fulfill the demand of water to meet required ET_c when precipitation is deficient for proper growth of crop till the final growth of crop. The irrigation system incorporates the utilization of the exact quantity of water at the correct time to crop for development of plant. Therefore, estimation of CWR and proper irrigation scheduling is required for irrigation water planning and management purpose (Ewaid *et al.,* 2019).

Wheat (*Triticum aestivum* L.) is one of the most significant grain crops on the earth. In the context of nutrients, wheat is a major source for approximately 40 percent of the world's population. It provides around 20 percent of the total food calories for humans (Giraldo, 2019). According to State Agriculture Plan and State Infrastructure Development Plan (SAP and SIDP) (2017-18 to 2019-20), Gujrat, wheat is grown on 0.9 – 1.6 M ha that comprises 23 % of the land used for cereals. The average wheat production and productivity in Gujarat were 38.12 lakh tonnes (2011- 12 to 2016-17) and 29.96 and 30.16 q/ha, respectively. Maximization of wheat production can be achieved through appropriate agronomic practices. Wheat required 278-373 mm of water through out season (Singh *et al.,* 2014). Proper irrigation practices are essential for proper management of wheat crop. For proper management, it is required to determine the CWR and irrigation scheduling of wheat.

Sorghum (*Sorghum bicolour* L. Moench) is the third most grain used in the world to feed the human population. Water stress can significantly affect sorghum yield potential. It

is essential to monitor soil moisture and apply irrigation when soil moisture depleted (Mundia *et al.,* 2019) for maintaining yield potential. Also, Rice has mostly consumed food for most of the world. Cultivation of rice through conventional methods takes about 50–300 cm of water (Bouman and Tuong, 2001), from which runoff and seepage loss is almost 50 – 80 percent. Shah *et al.,* (2015) reported that about 40-60 percent of water used by plants and the rest of the water lost from the field in the form of evapotranspiration, deep percolation, etc. CWR of paddy is estimated as 50.49cm for a part of hirakud command area and irrigation scheduling (Biswal and Rath, 2016). So, for all three major crops, the production can be increased by improving the irrigation scheduling method. Increasing crop production with available water resources is the challenge for the coming decades. Therefore, there is a serious need fora modified irrigation scheduling method (Koech *et al.,* 2018). The management of irrigation water involves proper irrigation scheduling (Chitu *et al.,* 2020). Irrigation scheduling includes two aspects: taking the decision to irrigate and executing it through a specific irrigation management approach. The principle irrigation system's decisions are (1) when to start the irrigation event, (2) how much irrigation solution to deliver during the irrigation event (Capraro *et al.,* 2019). Insufficient irrigation or over-irrigation could be responsible for reducing crop yields, quality, and poor nutrient use efficiency (Shah *et al.,* 2015). The irrigation scheduling help farmers to maximize yields and makes maximum use of soil moisture storage through less irrigation. Irrigation scheduling results in increasing crop yields that eventually results in increasing net returns. The CROPWAT model was found as an useful tool for scheduling irrigation under deficit irrigation conditions.

CROPWAT is one of the models that broadly utilized in the field of irrigation water management all over the world, which is developed by the Land and Water Development Division of the Food Agricultural Organization (FAO). Its primary function is to calculate ET_0, crop water, and irrigation water requirements, develop and manage proper scheduling of irrigation water, and design irrigation schemes. It allows the development of guidance for revise irrigation exercise, proper irrigation scheduling under different water contribute systems, and the production assessment under different irrigation exercises. CWR of Sorgum is estimated as 187.5mm for Waghodia Region, Vadodara district, Gujrat, India (Kumari, 2017). But the estimation of CWR for rice and wheat has not proposed in this paper. Considering this gap, the objective of this study are 1. To determine the crop water requirement and irrigation scheduling for Wheat, Sorghum, and Rice crop using CROPWAT 8.0 software, 2. To determine Reference Evapotranspiration and the effect of atmospheric parameters on it.

Materials and Methods

Study area

The study was conducted in Waghodia Region, Vadodara district, Gujarat, India (Latitude 22º30' N and Longitude 73º38' E) (Figure 1). The climate of the place is under the tropical region. The average annual rainfall of the study region was 96.4 cm. The average temperature is 27.3ºC. The average annual wind speed, humidity, and radiation were 2 km/day, 65%, and 18.1 MJ/m^2/day, respectively. Entire Gujarat is divided into various Agro-climatic zones, and the Vadodara district is covered in Agro climatic zones-3. The study area is under the Vadodara region and its command area located in Middle Gujarat.

Data collection

Meteorological data

The Meteorological data is taken from the literature published by Kumari, 2017. The wind speed, temperature (maximum and minimum), sunshine hours, relative humidity, and rainfall data (monthly) are considered. Reference evapotranspiration (ET_0) is also estimated using CROPWAT.

Crop data

The required data such as crop name, planting date, rooting depth of crop at different growing stages, critical depletion, crop coefficient, yield response factor, and harvesting data (Allen *et al.,* 1998) for sorghum, rice, and wheat crops are collected from FAO 56 manual (Table 1). Depletion factor, Crop Coefficient for Sorghum, Rice, and Wheat are also measured.

Soil data

Waghodia region has black clay type soil. The software needs some general soil data that has been obtained from the FAO 56 manual (Table 2).

Model description and setup

Land and Water Development Division of FAO, Italy, with coordination to Irrigation and Development Studies of Southampton, UK, and National Water Research Centre, Egypt developed a decision support system for windows called CROPWAT 8.0. It calculates CWR as well as water requirements for irrigation based on the soil, crop and climatic data. It also develops the irrigation schedule under different water supply systems and schemes of water supply for different cropping patterns. It can be used under rainfed as well as irrigated conditions to

assess the crop performance. In CROPWAT 8.0 model ET_0 is estimated using the FAO Penman-Monteith method (1992). Estimated ET_0 is used to estimate crop water and IWR and irrigation scheduling. Estimated IWR using CROPWAT 8.0 is either per week or per month period basis or according to the requirement of cropping pattern for the different growth stages of crop development of the crop in the irrigated region (Memon and Jamsa, 2018). In the schedule module of CROPWAT 8.0, the soil water balance is carried out daily.

Evapotranspiration

For estimation of reference evapotranspiration in CROPWAT 8.0 model, FAO Penman-Monteith equation is used (Smith *et al.,* 1998; Sentelhas *et al.,* 2010), which described as

$$ET_0 = \frac{0.408\,\Delta R_n + \gamma\left(\frac{900}{T_{mean}+273.16}\right)u_2\,(e_s - e_a)}{\Delta + \gamma\,(1 + 0.34\,u_2)} \quad (1)$$

Where, ET_0 = Reference Evapotranspiration,
R_n = Net solar radiation at the crop surface $(MJ/m^2/day)$,
T_{mean} = Daily mean maximum and minimum temperatures (^oC),
u_2 = Wind speed at standard 2 m height (m/s),
e_a = Actual vapor pressure (kPa), is the and
Δ = Slope of vapor pressure curve $(kPa/^oC)$,
e_s = Saturation vapor pressure (kPa),
γ = Psychrometric constant $(kPa/^oC)$ (=0.054).

Crop coefficient (K_c) is combined with reference evapotranspiration to calculate crop Evapotranspiration. The K_c values at three growth stages (i.e. initial, mid, end stage) are directly taken from Allen *et al.,* (1998), Pereira *et al.,* (2015).

$$ET_c = K_c \times ET_0 \quad (2)$$

Effective rainfall

The rainfall is the basic input for the determination of CWR. For satisfying CWR, the contribution of rainfall is important, depending upon the location of the study area. Effective rainfall is determined using Soil conservation service formula of USDA in CROPWAT 8.0 model.

For Monthly steps: for P rainfall,

$$P_{eff} = P*(125 - 0.2*P) / 125 \text{ for } P <= 250 \text{ mm} \quad (3)$$

$$P_{eff} = 125 + 0.1*P \text{ for } P > 250 \text{ mm} \quad (4)$$

Where, P_{eff} = Effective rainfall in mm,
P = Total rainfall in mm.

Irrigation scheduling

Irrigation scheduling helps to decide the precise quantity of the water for proper timely irrigation. Calculated ET_c, CWR, IWR are used for the development of scheduling of irrigation under different supply of water (Allen *et al.,* 2005).

Results and Discussion

Crop water requirements and Irrigation scheduling of three crops, i.e., Wheat, Rice, and Sorghum is estimated using CROPWAT.

Reference evapotranspiration

The values of reference evapotranspiration (ET_0) are simulated through CROPWAT 8.0 model using the Penman-Monteith equation. Monthly variation of ET_0 is estimated using meteorological parameters like temperature, humidity etc. for the Waghodia region (Figure 2). The ET_0 is minimum in December and January month, and attained its peak during the month of April-June and further declined

during the month of July-September. From Figure 1(a), it can be seen that the ET_0 is linearly increasing with Maximum temperature as compared to the minimum temperature. Whereas, from figure 1(b) it can be seen that ET_0 is inversely proportional to the relative humidity. From figure 1(c) and (d), it can be revealed that the ET_0 is directly proportional to the solar radiation and sunshine hours. ET_0 is highest (5.23 mm/day), and lowest value (1.9 mm/day) in May and December, respectively. The rainfall and air temperature have an impact on determination of ET_0. In conclusion, solar radiation is a powerful meteorological parameter for the estimation of ET_0.

Effective rainfall

Different method (Fixed percentage, Empirical formula, Dependable rain, and USDA Soil Conservation Service methods) are in CROPWAT 8.0 model for the estimation of the effective rainfall. Rainfall is observed to be zero (Figure 2) in the non-rainy season (month of Oct-May). In the rainy season, the effective rainfall is only 49-87% of the rainfall due to the losses. ET_0 is less in the rainy season and winter season as compared to summer. From Jul, Aug, and Sep month, it is observed that $ET_0$is varied with effective rainfall. The total average effective rainfall of the Waghodia region is found to be 527.6 mm, which is 58.16% of the total rainfall occurred. Figure 3 shows the monthly seasonal rainfall, effective monthly rainfall, and reference evapotranspiration for the Waghodia region.

Crop water requirement

In the present study, evaporative demand is estimated using the Penman-Monteith equation, and it is related to the crop's water use for growing periods. The model is calculated the CWR on a daily basis. Crop water and irrigation requirement of sorghum, rice, and wheat are given in Table 3. The total estimated water requirement for sorghum is found to be 241.3 mm. The required irrigation water is estimated by subtracting the effective rainfall from CWR. For the sorghum crop, it is found to be 188.8 mm which is nearly equal to the estimated CWR value proposed by Kumari (2017). The CWR data is slightly different from the Kumari (2017) because the transplantation data which we have considered from FAO data. For sorghum, irrigation water is required only in October, November, and December because there is no rainfall throughout these months to satisfy the CWR. For rice, the estimated CWR is 480.9 mm, and the IWR is found to be 343.3 mm. Irrigation is required in June and July for land preparation of rice and in October and November months for its growth. For wheat, IWR and CWR are found to be the same as 333.9 mm. Crop period of wheat is December to April, during which no rainfall occurs. Therefore, CWR is satisfied by irrigation water only. For all the three crops, the highest CWR is found in development and mid-stages and less requirement of water for crop in the initial and late stages.

Irrigation scheduling

Irrigation is scheduled based on climate data, including rainfall, humidity, sunshine hour, temperature and sowing date, soil characteristics, etc. using the CROPWAT 8.0 software. Irrigation Scheduling is calculated by maintaining critical depletion at 100%, restore the moisture content of soil to 100% field capacity. Seventy percent of irrigation efficiency is considered. Irrigation scheduling is estimated for three crops in Waghodia region.

Sorghum

Based on the study of daily rainfall and evapotranspiration data, irrigation is not required at initial and development stage, as

the effective rainfall is more than the ET_c. The crop sustained up to 63 days from sowing due to rainfall. After that first irrigation of 79.3 mm should be given to protect the crop from water-stressed conditions. Furthermore, the subsequent irrigation may be given after 93 days with 78.4 mm of net irrigation. Considering an efficiency of 70% during each irrigation supplied by flooding with an unavoidable loss due to various causes, the gross irrigation requirement during each irrigation will be 113.2 mm, 112.1mm. Irrigation scheduling of sorghum has been presented in Table 4, and the respective pictorial representation is shown in Figure 4.

Rice

Based on the study of daily rainfall and evapotranspiration data, it is observed that during initial, development, and mid-stage, there was no need of irrigation, because of effective rainfall was more than ET_c. However, before planting, there was a need for irrigation for land preparation, i.e., for pre-puddling and puddling, which is 19 and 4 days before plating with 96.6 mm and 84.9 mm irrigation, respectively. As this irrigation water is used for preparation and puddling purposes, the losses are neglected. Then subsequent irrigations should be given after 89, 104, and 121 days after sowing with 99.2 mm, 96.7 mm, and 95.4 mm of net irrigation, respectively. The gross irrigation for rice is 502.8 mm. Irrigation scheduling of rice presented in Table 5, and the respective pictorial representation is shown in Figure 5.

Table.1 Soil data for the study area

Crop	Sorghum	Rice	Wheat
Sowing Date	20 Aug	15 Jul	31 Dec
Harvesting Date	22 Dec	21 Nov	29 April
Crop Growing Stages (Day)			
Initial stage	20	30	15
Development Stage	35	20	25
Mid Stage	40	30	50
Late stage	30	50	30
Ranges of Maximum Effective Rotting Depth			
Max. Root Depth (m)	0.5 - 0.6	0.5 – 0.6	1.5 - 1.8
Soil water Depletion Fraction for No Stress			
Depletion Fraction (P)	0.55	0.5	0.55
Single Crop Coefficient K_c			
K_c (initial)	0.30	0.5	0.7
K_c (mid)	1.0	1.05	1.15
K_c (end)	0.55	0.70	0.25
Maximum Plant Heights			
Crop Height	1.2	1.0	1.0

Table.2 Soil data for the study area

Soil Type: Black Clay Soil	
Total available soil moisture (FC - WP)	150.0 mm/meter
Maximum rain infiltration rate	13 mm/day
Maximum rooting depth	90 cm
Initial soil moisture depletion (as % TAM)	50 %

Table.3 Crop water requirement and irrigation requirement of sorghum, rice, and wheat

Month	Sorghum		Rice		Wheat	
	Etc (mm/month)	Irri. Req. (mm/month)	Etc (mm/month)	Irri. Req. (mm/month)	Etc (mm/month)	Irri. Req. (mm/month)
Jan	0	0	0	0	55.3	55.3
Feb	0	0	0	0	81.2	81.2
Mar	0	0	0	0	115.2	115.2
Apr	0	0	0	0	80.8	80.8
May	0	0	0	0	0	0
Jun	0	0	22.5	102.6	0	0
Jul	0	0	99.4	84.9	0	0
Aug	10.9	0.9	101.8	0	0	0
Sep	42.4	0	101.3	0	0	0
Oct	92.3	92.2	107.1	107	0	0
Nov	68.7	68.7	48.8	48.8	0	0
Dec	27	27	0	0	1.4	1.4
Total	241.3	188.8	480.9	343.3	333.9	333.9

Table 4. Irrigation scheduling of sorghum

| Number of Irrigation	Day	Days after Planting	Stage	Depletion (%)	Net Irrigation (mm)	Gross Irrigation (mm)
1st	21-Oct	63	Mid	59	79.3	113.2
2nd	20-Nov	93	Mid	58	78.4	112.1
End	22-Dec	End	End	34		

Table.5 Irrigation scheduling of rice

Number of Irrigation	Day	Day after Planting	Stage	Depletion SM	Net Irrigation (mm)	Loss	Gross Irrigation (mm)
1st	25-Jun	-19	Pre-Puddling	39	96.6	0	96.6
2nd	10-Jul	-4	Puddling	0	84.9	0	84.9
3rd	11-Oct	89	End	0	99.2	10	109.2
4th	26-Oct	104	End	0	96.7	10	106.7
5th	12-Nov	121	End	0	95.4	10	105.4
End	21-Nov	End	End	0	0	0	0

Table.6 Irrigation scheduling of Wheat

Number of Irrigation	Day	Day after Planting	Stage	Depletion (%)	Net Irrigation (mm)	Gross Irrigation (mm)
1st	01-Jan	2	Initial	57	24.1	34.5
2nd	17-Jan	18	Dev	56	45.2	64.6
3rd	07-Feb	39	Dev	55	73.6	105.1
4th	04-Mar	64	Mid	56	76.2	108.8
5th	25-Mar	85	Mid	57	77.2	110.3
6th	15-Apr	106	End	56	75.7	108.1
End	29-Apr	End	End	21		

Figure.1 Waghodia region and its location in India
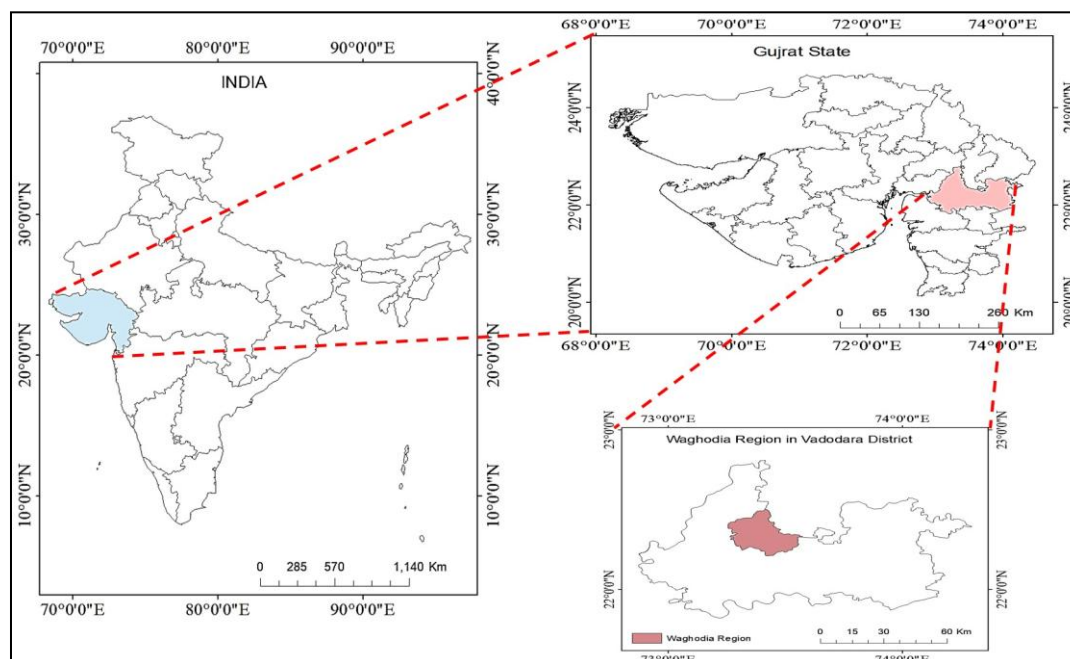
Figure.2 Monthly variation of reference evapotranspiration (ET$_0$), with (a) Max and Min Temperature, (b) Humidity, (c) Sunshine Hour, (d) Solar radiation
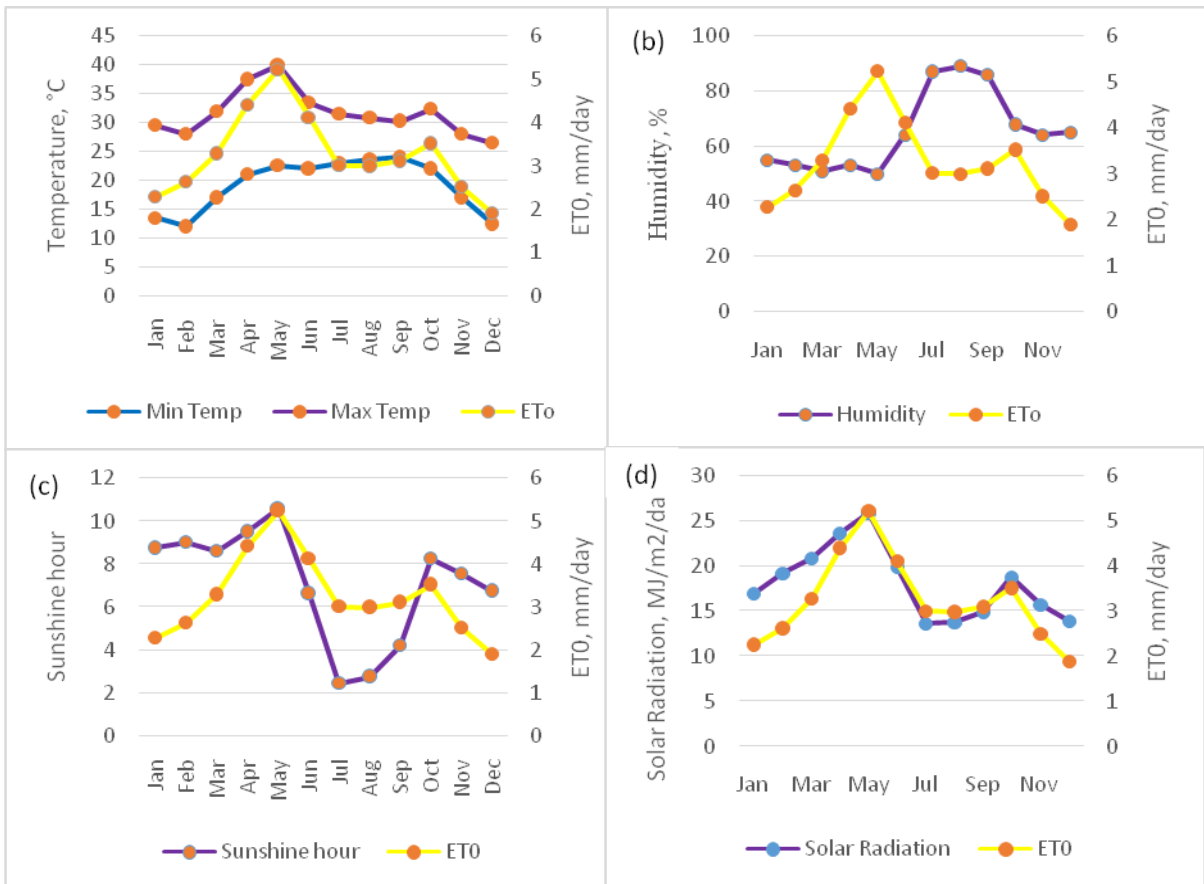
Figure.3 Monthly variation of Reference Evapotranspiration (ET$_0$) with rainfall and effective rainfall at Waghodia Region
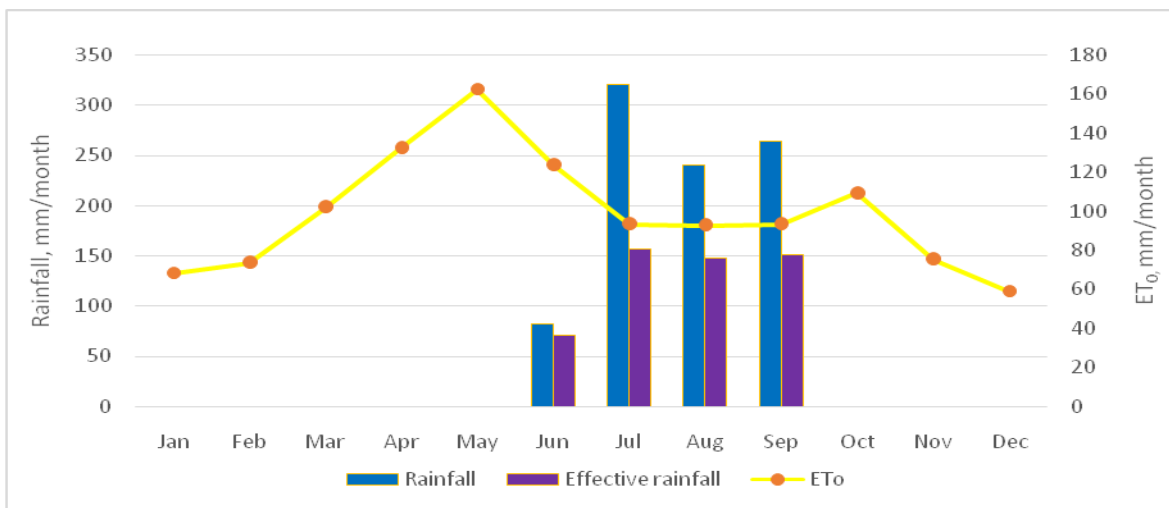

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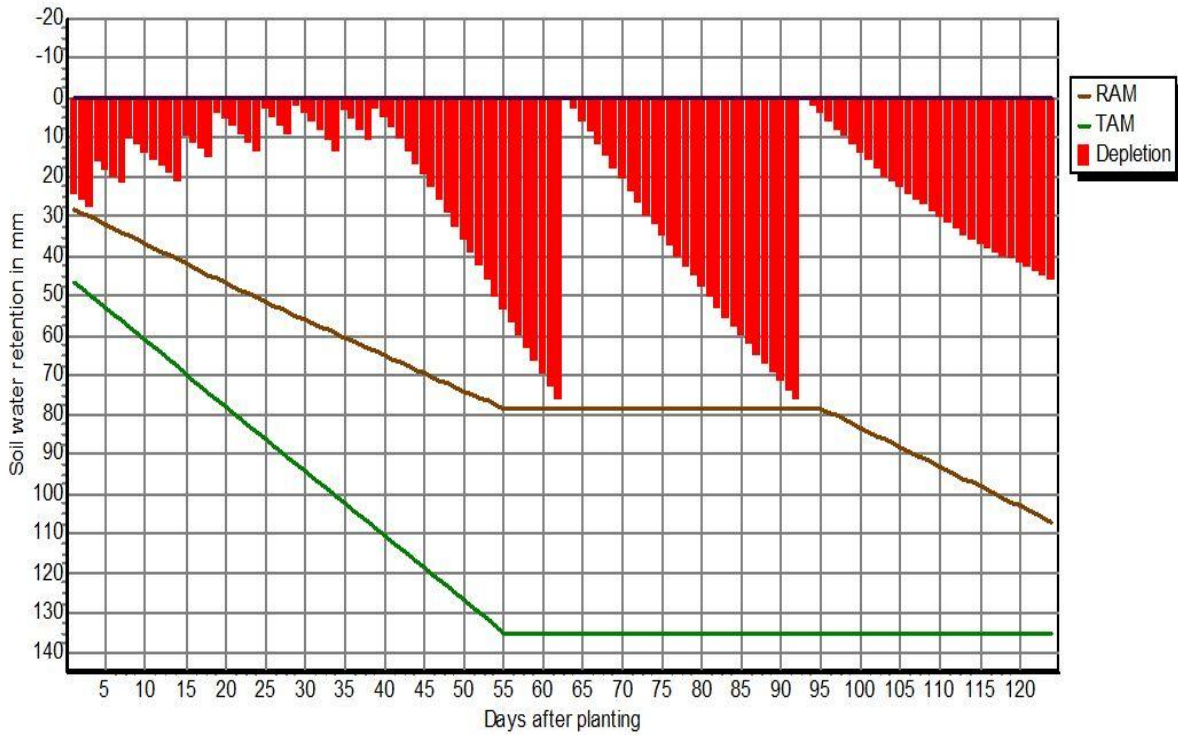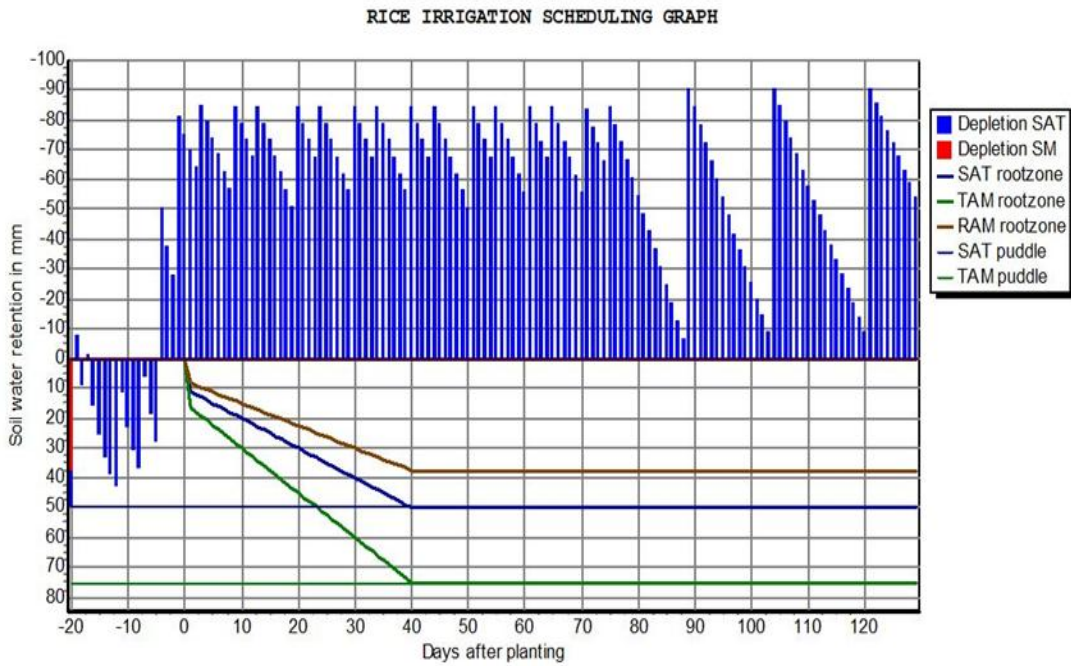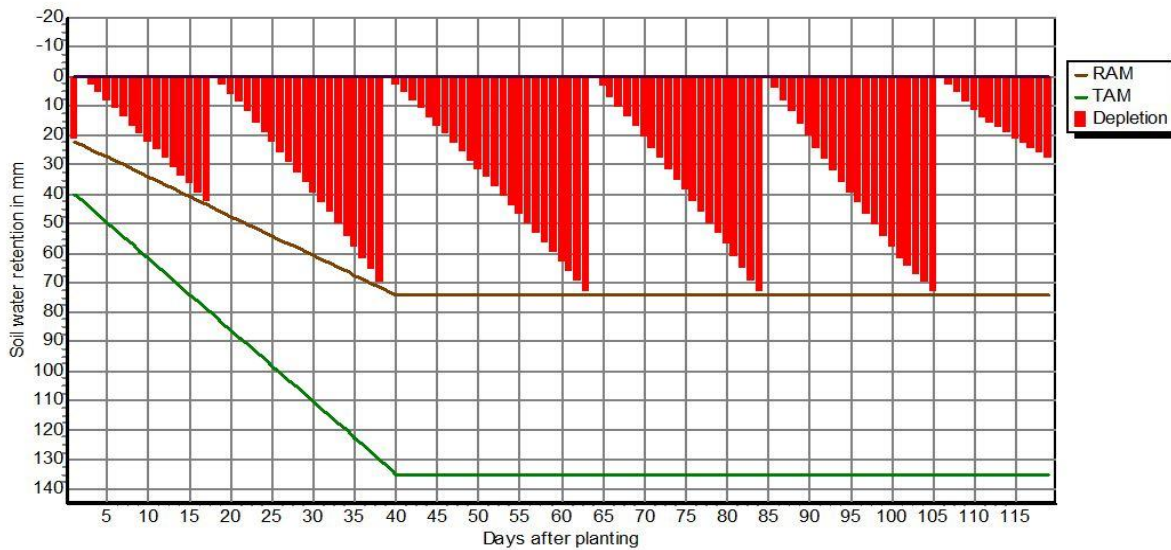**Figure.4** Pictorial representation of irrigation scheduling of sorghum

Figure.5 Pictorial representation of Irrigation scheduling of rice (SAT was the depletion of saturation, which was the amount of water below saturation moisture soil content)

Figure.6 Pictorial representation of irrigation scheduling of wheat

Wheat

During the crop period of wheat, there was no rainfall. So the irrigation should be provided throughout the crop period. Irrigations is scheduled on 2, 18, 39,64, 85, 106 days after sowing with the net irrigations of 24.1 mm, 45.2 mm, 73.6 mm, 76.2 mm, 77.2 mm, and 75.7 mm respectively. The gross irrigation for wheat is estimated as 531.4 mm. Irrigation scheduling of wheat is presented in Table 6. and the respective pictorial representation shown in Figure 6.

From the irrigation scheduling of all the three crops, it is observed that rice and sorghum required less irrigations in rainy season as compared to wheat crops in the non-rainy season. During non-rainy season CWR is to be fulfilled by irrigation only. So the number of irrigations increased, and irrigation may provided according to schedule throughout the crop period and this methodology can be adopt for irrigation scheduling for this particular study area.. From all three crops, the highest water required for rice with 820 mm without considering the nursery stage.

In conclusions, the reference evapotranspiration, crop water requirement, and irrigation scheduling computed with the help of the CROPWAT 8.0 model is developed by FAO using the crop, soil, and climatic data. The ET_0 of study area is directly proportional with solar radiation, and sunshine hours and inversely proportional with relative humidity. The average daily ET_0 is found to be 3.25 mm/day, and it is varied between 5.23 and 1.9 mm/day. The total average effective rainfall estimated at 527.6 mm/day, and it is estimated as 58.16% of the total rainfall. The CWR for sorghum, rice, and wheat are found to be 241.3 mm, 480.9 mm, and 333.9 mm, respectively. The IWR of these crops is estimated by subtracting the effective rainfall from CWR, which is estimated as 188.8 mm, 343.3 mm, and 333.9 mm for sorghum, rice, and wheat, respectively. The net water requirement of sorghum, rice, and wheat is estimated as 157.7 mm, 472.8 mm, and 372 mm, respectively. Moreover, the gross water requirement for sorghum, rice, and wheat is obtained as 225.3mm, 502.8 mm, and 531.4 mm, respectively. Thus, CROPWAT can deliver practical guidance to farmers on

shortfall irrigation scheduling in various crop, soil, rainfall, and climatic conditions.

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