Madras Agric. J., 2021; doi:10.29321/MAJ.10.000494(online first)

RESEARCH ARTICLE

Estimation of Crop Water Requirement for Sugarcane in Coimbatore District using FAO CROPWAT

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ABSTRACT

The present study aimed to evaluate the software CROPWAT 8.0 that is used for estimation of the crop water requirement forsugarcane. With these approach the net irrigation requirement of sugarcane is calculated and the monthly water requirement is calibrated to meet out the requirement. It includes a simple water balance model that allows the simulation of crop water stress conditions and estimation of yield reductions based on well-established methodologies. The use of modern irrigation techniques will go a long way in reducing water use and conservation. This will put wider areas under cultivation and potentially contribute to greater agricultural production. The results showed that the Net and Gross Irrigationare 1394 and 1991.5 mm, repectively. The crop water requirement of sugarcane in Coimbatore was estimated to be 1438.7 mm.

Keywords: CROPWAT, Crop water requirement, Irrigation Scheduling,Irrigation water requirement.

INTRODUCTION

Water the most essential and basic need of anything and everything of humans. Urbanization and Globalization are leading the world to the scarce of water resources.To overcome the scarcity of water for agriculture, planning of the crop and its management is necessary. Crop water requirement was estimated using CROPWAT 8.0 software based on the crop and the spatial weather data. Sugarcane is one of the annual crops, which requires water throughout the year.By proper planning and assessment of irrigation crop water requirements tend to increase the yield and to effectively utilize the available water, thereby we can manage the scarcity of water.

Serious water deficiencies are creating in numerous nations, especially in India and water for farming is turning out to be progressively rare, in the light of developing water requests from various parts (IWMI 2010). Agriculture is the biggest consumer of water in India and hence more efficient use of water in agriculture needs to be given more importance by adopting new technologies (Thiyagarajan *et al.,* 2011 and Surendran *et al.,* 2013). Due to the change in the climate and urbanization, there is a huge need for water for the survival and agricultural production. As we are now facing the shortage of water for agriculture, effective water utilization is the only way to overcome the scarcity of water for agriculture. To meet the future population, urbanization and various crop diseases, increased demand for irrigation water which may lead to the scarcity of agricultural products. one of the effective ways is to increase the crop production rate and to precisely using the available water to increase the yield to meet out the future requirements. Many studies indicate the rise in the demand for irrigation water in global and local level, which may significantly affect the agricultural scenario very soon.

In an environment in which the rapid climate change is happening and its environmental effects like monsoon failure, melting of glaciers, and high-intensity short duration rainfalls, which may lead to droughts and floods and will directly affect the human society as well as the farming society. Prediction of the crop water requirement is vital in water resources management and in planning the crop and its yield. Crop water requirements are normally expressed by the rate of evapotranspiration (ET) in mm day^{-1}. One of the significant practices embraced by the scientists for water requirements is modeling. To Model the Crop water requirement, many field level data must be validated and correlated to be fed into CROPWAT Software. For determination of crop water requirement, crop evapotranspiration and yield responses to water, CROPWAT 8.0 model is used, which was developed by the FAO Land and Water Development Division (FAO, 1992).

Using the crop water requirement obtained from the CROPWAT, the farmers and researchers may be

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able to predict the seasonal and crop water needs and can plan for the crop and may be able to reduce the losses and increase the yield.

MATERIAL AND METHODS

Study Location

Coimbatore District in the state of Tamil Nadu and lies in the GPS coordinates of 11° 0' 16'' N and 76° 57' 41'' E at a mean sea level of 411m. The district has an area of 4723 km^2. The average rainfall of this area is about 618 mm.The third-largest city of the state, Coimbatore, is one of the most industrialized cities in India. It is known as the the Manchester of the South, the city is situated on the banks of the river Noyyal. The city has a well-planned tank irrigation system that stores the Noyyal River water during the monsoon and was utilized for the Summer season, which is one of the important reasons for the boom of Agriculture in Coimbatore. The Location area map is presented in Figure 1.

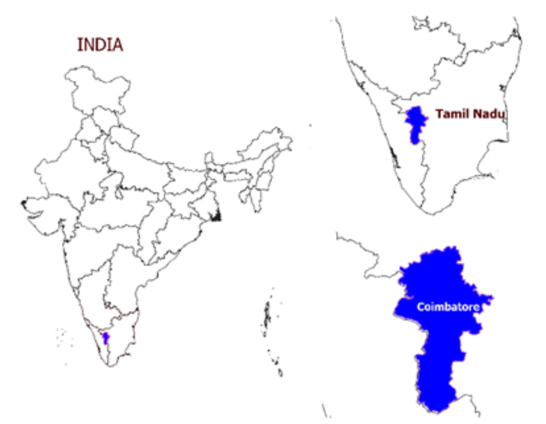


Figure 1. Study Area Map

Meteorological data

The district lies in the rain shadow region of the Western Ghats and experiences pleasant climate most parts of the year. The mean maximum and minimum temperatures for Coimbatore city during summer and winter vary between 35°C to 18°C. Long-term weather data was collected from IMD, Chennai for Coimbatore District. The essential parameters include: Maximum and Minimum Temperature, Relative Humidity, Wind speed and sunshine Hours. Nearly 80% of rainfall in India is received during the monsoon period. Monsoon rainfall is very uncertain. So, irrigation is very important to supply water to plants also and when needed. To compensate the uneven distribution in an area, supplemental irrigation is needed.

Crop data

Coconut is the major plantation crop cultivated in an area of about 85831Ha. The other Agricultural crops cultivated are Millets, Pulses, Oilseeds, Cotton and Sugarcane. Sugarcane was sown in area of 927 ha and the production is about 121181 tonnes. At least 850 mm of water per year is required for sustainable rainfed production of sugarcane.High-yielding crops like sugarcane produce heavy biomass and economic yield. Higher biomass needs more water for its production. Hence supplementation of water as irrigation is essential. For commercial production, full irrigation was practiced when annual rainfall is less than 800 mm and supplemental irrigation is applied when annual rainfall is less than 1000 mm.

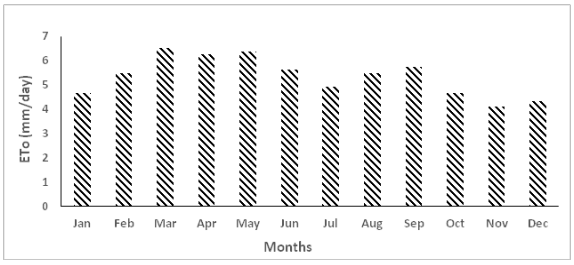


Figure 2. Monthly distribution of reference evapotranspiration

The Sustainable Sugarcane Initiative (SSI) aims at providing practical options to the farmers in improving the productivity of land, water and labor, all at the same time. SSI is also expected to reduce the overall pressure on water resources and contribute to the recovery of ecosystems. Sustainable Sugarcane Initiative is an innovative method of sugarcane production using less seeds, less water and optimum utilization of fertilizers and land to achieve more yields (agritech.tnau.ac.in).

CROPWAT 8.0 MODEL

CROPWAT 8.0 is a decision support tool developed by the Land and Water Development Division of FAO. CROPWAT for Windows is a computer program for the calculation of crop water requirements and irrigation requirements based on soil, climate and crop data. CROPWAT 8.0 can also be used to evaluate farmers' irrigation practices and to estimate crop performance under both rainfed and irrigated conditions. In addition, the program allows

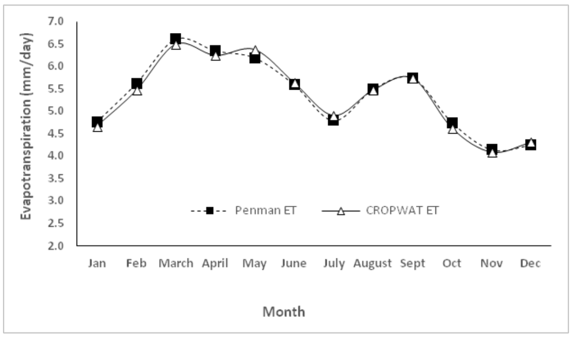


Figure 3. Comparison of ET values obtained from Penman method and Cropwat software

the development of irrigation schedules for different management conditions and the calculation of scheme water supply for varying crop patterns. The development of irrigation schedules in CROPWAT 8.0 is based on a daily soil-water balance using various user-defined options for water supply and irrigation management conditions. Scheme water supply is calculated according to the cropping pattern defined by the user, which can include up to 20 crops(Smith, 1992). Thiyagarajan and Ranghaswami(2010) used the FAO CROPWAT software for irrigation scheduling and croop planning.

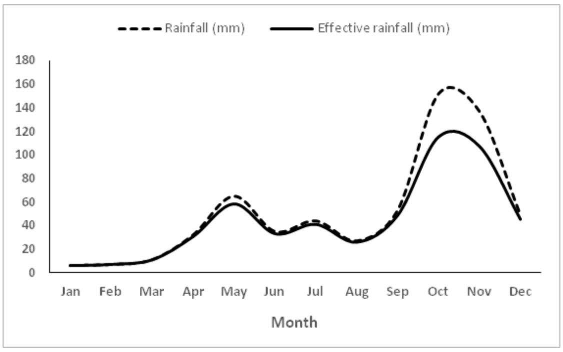
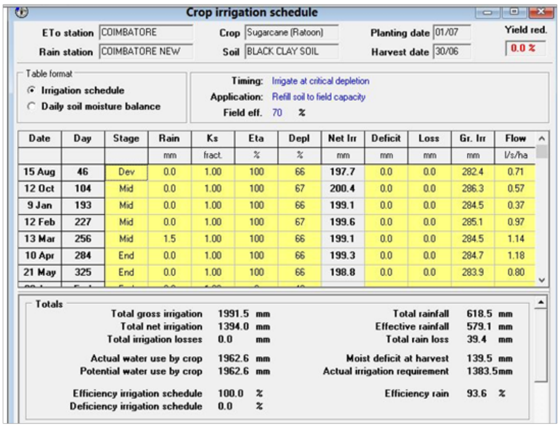


Figure 4.Effective Rainfall

Reference Evapotranspiration

In CROPWAT, the reference evapotranspiration can be fed directly through the meteorological data or that which can be estimated by providing the monthly climate data by using the Penman-Monteith equation. The concept of the reference evapotranspiration was introduced to study the evaporative demand of the atmosphere independently of crop type, crop development and management practices (Allen *et al.,* 1998).



Crop irrigation schedule

ETo station COIMBATORE · Crop Sugarcane (Ratoon) · Planting date 01/07 · Yield red. 0.0 %
Rain station COIMBATORE NEW · Soil BLACK CLAY SOIL · Harvest date 30/06

Table format: Irrigation schedule / Daily soil moisture balance
Timing: Irrigate at critical depletion
Application: Refill soil to field capacity
Field eff. 70 %

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
15 Aug	46	Dev	0.0	1.00	100	66	197.7	0.0	0.0	282.4	0.71
12 Oct	104	Mid	0.0	1.00	100	67	200.4	0.0	0.0	286.3	0.57
9 Jan	193	Mid	0.0	1.00	100	66	199.1	0.0	0.0	284.5	0.37
12 Feb	227	Mid	0.0	1.00	100	67	199.6	0.0	0.0	285.1	0.97
13 Mar	256	Mid	1.5	1.00	100	66	199.1	0.0	0.0	284.5	1.14
10 Apr	284	End	0.0	1.00	100	66	199.3	0.0	0.0	284.7	1.18
21 May	325	End	0.0	1.00	100	66	198.8	0.0	0.0	283.9	0.80

Totals

Total gross irrigation	1991.5 mm	Total rainfall	618.5 mm
Total net irrigation	1394.0 mm	Effective rainfall	579.1 mm
Total irrigation losses	0.0 mm	Total rain loss	39.4 mm
Actual water use by crop	1962.6 mm	Moist deficit at harvest	139.5 mm
Potential water use by crop	1962.6 mm	Actual irrigation requirement	1383.5mm
Efficiency irrigation schedule	100.0 %	Efficiency rain	93.6 %
Deficiency irrigation schedule	0.0 %		

Figure 5. Net irrigation and gross irrigation obtained from FAO CROPWAT

Evaporation and transpiration happen at the same time and there is no simple method of recognizing the two forms. When the crop is small, the predominantly water Loss by soil evaporation, but once the crop grows well and the soil covers fully, transpiration is the key method.

Penman-monteith method

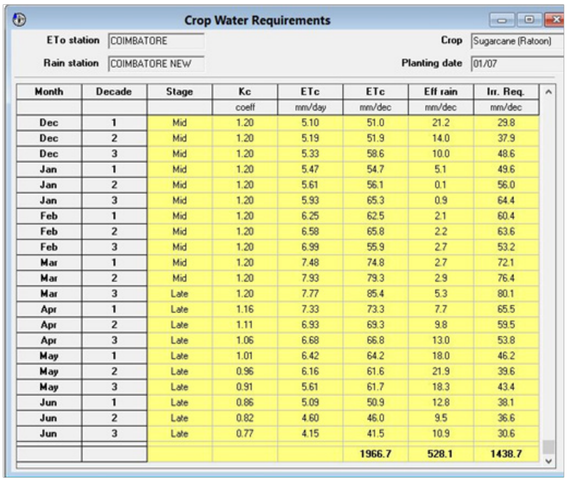
The FAO-Penman-Montieth equation is recommended as the standard method for estimating reference evapotranspiration.In 1948, Penman combined the energy balance with the mass transfer method and derived an equation to compute the evaporation from an open water surface from standard climatological records of sunshine, temperature, humidity and wind speed. One can interpret the equation as the peak water that could be evapotranspired at the given air and surface characteristics due to the solar and wind energy in the system(Allen *et al.,* 1998).

The Penman-Monteith form of the combination equation is

$$ETo = \frac{0.408\Delta(Rn\text{-}G)+\gamma\,(900/T+273)u2(es\text{-}ea)}{\Delta+\gamma(1+0.34u2)}$$

Where,

ETo is reference evapotranspiration (mm day^{-1}), Rn is net radiation at the crop surface (MJ m^{-2} day^{-1}),G is soil heat flux density (MJ m^{-2} day^{-1}),T is air temperature at 2 m height (°C),u2 is wind speed at 2 m height (m s^{-1}), es is saturation vapour pressure (kPa), ea is actual vapour pressure (kPa), es - ea is saturation vapourpressure deficit (kPa), Δ is slope vapour pressure curve (kPa °C^{-1}),Y is psychometric constant (kPa °C^{-1}).



Crop Water Requirements

ETo station COIMBATORE · Crop Sugarcane (Ratoon)
Rain station COIMBATORE NEW · Planting date 01/07

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Dec	1	Mid	1.20	5.10	51.0	21.2	29.8
Dec	2	Mid	1.20	5.19	51.9	14.0	37.9
Dec	3	Mid	1.20	5.33	58.6	10.0	48.6
Jan	1	Mid	1.20	5.47	54.7	5.1	49.6
Jan	2	Mid	1.20	5.61	56.1	0.1	56.0
Jan	3	Mid	1.20	5.93	65.3	0.9	64.4
Feb	1	Mid	1.20	6.25	62.5	2.1	60.4
Feb	2	Mid	1.20	6.58	65.8	2.2	63.6
Feb	3	Mid	1.20	6.99	55.9	2.7	53.2
Mar	1	Mid	1.20	7.48	74.8	2.7	72.1
Mar	2	Mid	1.20	7.93	79.3	2.9	76.4
Mar	3	Late	1.20	7.77	85.4	5.3	80.1
Apr	1	Late	1.16	7.33	73.3	7.7	65.5
Apr	2	Late	1.11	6.93	69.3	9.8	59.5
Apr	3	Late	1.06	6.68	66.8	13.0	53.8
May	1	Late	1.01	6.42	64.2	18.0	46.2
May	2	Late	0.96	6.16	61.6	21.9	39.6
May	3	Late	0.91	5.61	61.7	18.3	43.4
Jun	1	Late	0.86	5.09	50.9	12.8	38.1
Jun	2	Late	0.82	4.60	46.0	9.5	36.6
Jun	3	Late	0.77	4.15	41.5	10.9	30.6
					1966.7	528.1	1438.7

Figure 6. Crop Water Requirement obtained from FAO CROPWAT

Effective rainfall

The rainfall contributes to a greater or lesser extent in supporting Crop Water Requirement, depending on the study area and time of rainfall. During the rainy season in arid and semi-arid regions, a great part of the crop's water needs is covered by rainfall, while during the dry season, the major supply ofwater should come from irrigation. Effective rainfall is equal to the difference between total rainfall and actual evapotranspiration.The effective rainfall is the rainfall eventually used to determine the net irrigation requirements. Effective rainfall can be calculated directly from the climatic parameter and usable water resources.

It is the part of rainfall, which is stored in the soil profile and helps in the growing of crops. To calculate the effective rainfall the USDA Soil Conservation Service method was used (Smith, 1991). Where P_{eff} represents effective rainfall (mm) and P_{tot}represents total rainfall (mm).

Effective Rainfall is estimated by the USDA formula (i) and (ii)

$$Peff= \frac{Ptot \times(125-0.6Ptot)}{125} ,forP_{tot}<=(250/3)\ mm \quad (i)$$

$$Peff= \frac{125}{3} +0.1X\ Ptot,\ forP_{tot}<=(250/3)\ mm \quad (ii)$$

Where,

P_{eff}= Effective Rainfall (mm)

P_{tot} = Total Rainfall (mm)

Crop evapotranspiration

Crop characteristics, ground cover and development stage, soil water availability and meteorological criteria, or evaporative requirement, are the key determinants of evapotranspiration levels. When soil water is not a constraint and the crop is in an active growth stage with complete ground cover, maximum or possible evapotranspiration (ETp) occurs.For calculation of crop evapotranspiration FAO CROPWAT 8.0 model uses crop coefficient approach and the crop water requirements of various crops were calculated by summing up the crop evapotranspiration at all stages of crop development.

The crop type, variety and development stage should be considered when assessing the evapotranspiration from crops grown in large, well-managed fields. Differences in resistance to transpiration, crop height, crop roughness, reflection, ground cover and crop rooting characteristics result in different ET levels in different types of crops under identical environmental conditions (Allen *et al.,* 1998).

ET crop = Kc × E_{To}

Where,

ET_{C} – Crop Evapotranspiration

Kc – Crop Coefficient

ETo- Reference Evapotranspiration

RESULTS AND DISCUSSION

Reference Evapotranspiration (ETo)

The Penman–Monteith equation for calculating average reference evapotranspiration assumes evapotranspiration from a hypothetical crop with a height of 0.12 m, a surface resistance of 70 s m^{-1}, and an albedo of 0.23, which closely resembles the evaporation of an extension surface of grass cover of uniform height, steadily developing, and adequately watered. (Allen *et al* 1998).

Table 1. Reference Evapotranspiration along with meteorological parameters

Month	Min Temp (°C)	Max Temp (°C)	Humidity (%)	Wind (km/day)	Sun (Hours)	Rad (MJ/m²/day)	ETo (mm/day)
January	19.2	29.7	57	156	9.7	21.3	4.67
February	20.2	32.2	49	156	10.1	23.3	5.47
March	22.1	34.7	46	170	10.9	25.9	6.5
April	23.4	34.6	58	168	10.1	25.1	6.25
May	23.6	33.5	65	254	10.1	24.7	6.38
June	22.5	30.5	69	391	7.3	20.1	5.64
July	22	29	72	391	5.8	17.9	4.91
August	22.1	29.9	71	357	8.1	21.7	5.48
September	22	30.7	69	314	9.3	23.4	5.74
October	22	30.4	72	187	7.9	20.3	4.66
November	21.1	29.3	70	129	8	19.1	4.1
December	19.6	28.9	63	146	9.5	20.4	4.31
Average	21.6	31.1	63	235	8.9	21.9	5.34

The exact simulation of crop reference evapotranspiration (ETo) in semi-arid regions is essential for better irrigation management and irrigation scheduling of crops.The simulated values of reference evapotranspiration (ETo) through CROPWAT 8.0 model using Penman-Monteith equation, for the Coimbatore district along with the meteorological parameters is presented in Table 1 and monthly distribution of reference evapotranspiration is shown in Figure 2.

Table 2. Crop Water Requirement of Sugarcane in Coimbatore District

Month	Decade	Stage	Kc	Etc (mm/day)	Etc (mm/dec)	Eff rain (mm/dec)	Irr. Req. (mm/dec)
Jul	1	Init	0.40	2.04	20.4	13.5	6.9
Jul	2	Init	0.40	1.93	19.3	14.7	4.6
Jul	3	Deve	0.40	2.02	22.2	12.7	9.6
Aug	1	Deve	0.49	2.58	25.8	9.1	16.7
Aug	2	Deve	0.62	3.40	34.0	6.9	27.2
Aug	3	Deve	0.76	4.24	46.6	10.0	36.7
Sep	1	Deve	0.90	5.16	51.6	12.3	39.3
Sep	2	Deve	1.04	6.05	60.5	14.1	46.4
Sep	3	Mid	1.16	6.35	63.5	22.2	41.3
Oct	1	Mid	1.20	6.04	60.4	33.3	27.1
Oct	2	Mid	1.20	5.60	56.0	41.8	14.2
Oct	3	Mid	1.20	5.38	59.1	39.8	19.4
Nov	1	Mid	1.20	5.15	51.5	38.2	13.3
Nov	2	Mid	1.20	4.93	49.3	38.2	11.1
Nov	3	Mid	1.20	5.01	50.1	30.5	19.7
Dec	1	Mid	1.20	5.10	51.0	21.2	29.8
Dec	2	Mid	1.20	5.19	51.9	14.0	37.9
Dec	3	Mid	1.20	5.33	58.6	10.0	48.6
Jan	1	Mid	1.20	5.47	54.7	5.1	49.6
Jan	2	Mid	1.20	5.61	56.1	0.1	56.0
Jan	3	Mid	1.20	5.93	65.3	0.9	64.4
Feb	1	Mid	1.20	6.25	62.5	2.1	60.4
Feb	2	Mid	1.20	6.58	65.8	2.2	63.6
Feb	3	Mid	1.20	6.99	55.9	2.7	53.2
Mar	1	Mid	1.20	7.48	74.8	2.7	72.1
Mar	2	Mid	1.20	7.93	79.3	2.9	76.4
Mar	3	Late	1.20	7.77	85.4	5.3	80.1
Apr	1	Late	1.16	7.33	73.3	7.7	65.5
Apr	2	Late	1.11	6.93	69.3	9.8	59.5
Apr	3	Late	1.06	6.68	66.8	13.0	53.8
May	1	Late	1.01	6.42	64.2	18.0	46.2
May	2	Late	0.96	6.16	61.6	21.9	39.6
May	3	Late	0.91	5.61	61.7	18.3	43.4
Jun	1	Late	0.86	5.09	50.9	12.8	38.1
Jun	2	Late	0.82	4.60	46.0	9.5	36.6
Jun	3	Late	0.77	4.15	41.5	10.9	30.6
TOTAL					**1966.7**	**528.1**	**1438.7**

The ET values were obtained from both the Penman-Monteith method and also obtained from the CROPWAT software and are closely related to each other and from this, we can able to validate that the ET values obtained from the CROPWAT software can be used for the estimation of Crop water Requirements in field level and those results are to be accurate as such of the results of the Penman-Monteith method. The comparison of both the methods is graphically plotted in Figure 3.

Table 3. Estimated Crop Water Requirement of Sugarcane in Coimbatore District

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	TOTAL
Sugarcane	170	177.6	229	182.5	133	108.5	22.7	71.6	122	60.5	45.1	116.2	1438.7

From the result, it is revealed that the maximum ET_0 was found in May month (6.38 mm/day), which was mainly due to high temperature and more sunshine hours, whereas it was minimum in December (4.10 mm/day) due to the lower temperature.The reference evapotranspiration is the feature of temperature and is affected by Relative Humidity (RH).

Table 4. Net Irrigation Scheme

Net scheme irr.req.	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
in mm/day	1.6	1.9	2.2	1.8	1.3	1.1	0.2	0.7	1.2	0.6	0.4	1.1
in mm/month	51	53.2	68.7	54.7	39.9	32.6	6.8	21.5	35.4	18.2	13.2	34.9
in l/s/h	0.19	0.22	0.26	0.21	0.15	0.13	0.03	0.08	0.14	0.07	0.05	0.13

Effective rainfall

The effective rainfall was calculated for the study area with the help of USDA SCS method, which is presented in Figure 4. This will help for the estimation of irrigation water requirement of Sugarcane crops for the same area. Not all the rainfall obtained is used by the plants,some parts of rainfall are incurred as loses and the remaining amount of rainfall will be applicable for the efficient use of the crop for its growth and cultivation and hence effective rainfall is considered for the Crop water requirement estimation and all water balance-related studies. In general, the efficiency of rainfall decreases with the increasing rainfall.

Table 5. Net Irrigation Scheme Required for Actual Area

Net scheme irr. req.	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Irrigated area (% of total area)	30	30	30	30	30	30	30	30	30	30	30	30
Irr. req. for actual area (l/s/h)	0.63	0.73	0.85	0.7	0.5	0.42	0.08	0.27	0.46	0.23	0.17	0.43

It was found from the study that the total average effective rainfall is 527.7 mm which is 85.3 percent of the average annual rainfall 618 mm. The average effective rainfall was maximum in October (115 mm) followed by November (107 mm) and the lowest Effective Rainfall was recorded in January (5.9 mm).

Crop water requirement

The amount of water required to compensate for the evapotranspiration loss from the cropped field is defined as crop water requirement. While the values for crop evapotranspiration and crop water requirement are similar, crop water requirement refers to the amount of water that needs to be supplied, while crop evapotranspiration refers to the amount of water that is lost through evapotranspiration(Allen *et al.,* 1998).This may differ due to the local weather parameters and the type of crop cultivated in that area. The irrigation water requirement represents the difference between the crop water requirement and effective rainfall.

As per the Net irrigation and the Gross Irrigation obtained from the data are 1394 and 1991.5 mm respectively which are presented in the Table 2 and Figure 5. The Crop Water requirement of sugarcane for Coimbatore district is 1438.7mm. The estimated Crop water requirement of Sugarcane crop for Coimbatore district has been presented in Table 3 and the Water demands are represented in Figure 6. The Net Irrigation Requirement is presented in the Table 4 and the NIR for actual area of 30 % is presented in Table 5.

CONCLUSION

From this study, the difference in ETo is attributed to the combined effects of temperature,sunshine hours, radiation, wind speed and humidity. The increase in ETo from February to September can be explained by a change in temperature because in this period, we obtained the highest temperature. The ETo decreases in the late months are because of the low temperature.The findings also showed that when there is no rain, the crop water need was higher than rainy period. The average ETc and IR values varied depending on the soil type and conditions. And the changes in the water requirement for the seasons can be understood by the data of evapotranspiration Climate patterns vary over time and between seasons, causing crops to grow at different rates.

The monthly and total water requirements for the sugarcane crop in the Coimbatore district are estimated using FAO CROPWAT software. By estimating the water requirement for the sugarcane crop prior to the cropping season and the farmers in the study area can plan for the effective utilization of resources such as land and water. It will lead to preserve and conserve the resources for the next cropping season.

The Crop water requirement estimation has been a tool to estimate, Plan, and to schedule the irrigation and can be used for crop planning. To meet out the future water needs, the concepts of virtual water and water economics must be studied and those must be spread along with the research community. To enhance the proper water management strategies and to ensure the enforcement of water laws, policy and rules to properly utilize the available water.

The Results from CROPWAT show the way to easily simulate the crop water needs,plan and to schedule the irrigation and to plan the crop. This highlights the importance of scientific research for irrigation water distribution. The Evapotranspiration and Net Irrigation Requirement results provide a realistic evaluation of irrigation scheduling for the crops grown. These findings can be used to improve water use productivity and irrigation efficiency by properly controlling irrigation water withdrawal and application volumes, allowing irrigated agriculture to produce more crop yield in sugarcane crops in the Coimbatore district.

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