Winner of SADHNA Best Paper Award 2021

Modeling the crop water requirement and irrigation scheduling of banana using CROPWAT 8 model: a case study of Manali watershed, Thrissur, Kerala

PANCHAMY BALAN and ASHA JOSEPH

Department of Irrigation and Drainage Engineering
Kelappaji College of Agricultural Engineering and Technology (KAU)
Tavanur, Malappuram 679573 Kerala, India
Email for correspondence: panchamy1996@gmail.com

Received: 27.02.2021/Accepted: 17.04.2021

ABSTRACT

CROPWAT is a widely accepted model for calculating crop water requirement. In the present study an effort has been made to calculate the crop water requirement and irrigation scheduling of banana for two seasons in Manali watershed in Thrissur district of Kerala using CROPWAT 8 model. The climatic data for a period of 30 years (1988-2018) were collected from KAU, Vellanikkara, Kerala. Secondary data sources were consulted to obtain data related to crop and soil. The crop water requirement of banana was found to be 1,063.5 and 1,144.5 mm/dec for rainfed and irrigated crop respectively. The irrigation requirement of rainfed and irrigated banana crop was found to be 499.8 and 700.1 mm/dec respectively.

Keywords: CROPWAT; crop water requirement; irrigation scheduling; watershed; banana

INTRODUCTION

Though there is no change in the quantum of water available in hydrological cycle yet the amount of fresh or good quality water which is capable of meeting the various requirements is decreasing. That is on a global scale that it is abundant in quantity but spatial and temporal availability of fresh water is a problem. In India largest quantity of water (81%) is used for agriculture purposes (Surendran et al 2013). The case of Kerala is also not much different. Though Kerala is receiving high amount of rainfall, its temporal distribution is highly uneven that results in a moisture stress period of 14 to 15 weeks in south Kerala and 18 to 21 weeks in north Kerala (Varadan 1996). It is through irrigation, water is supplied to the crops in the days when there is no availability of water from rainfall. But in Kerala irrigation recommendations are of general nature and do not account for all soil types and climate (Allen et al 1998).

The irrigation schedule recommendations should be location specific for each crop considering the soil types and agro-ecological conditions. The scientific crop water requirements are required for efficient irrigation scheduling, water balance and efficient water resources planning. In Kerala there is lack of information on crop water requirement of various crops. The total quantity of water required to counteract the water loss due to evapotranspiration from cropped field is known as crop water requirement and quantity of water applied in addition to rainfall to satisfy the crop water requirement is called as irrigation requirement.

From the point of view of water resource management, the correct assessment of crop water requirement and its adequate supply increase the crop production. Water use efficiency can be increased by planning proper irrigation scheduling. Hence in this paper an attempt has been made to compute the crop water requirement and irrigation scheduling of banana (two seasons) in Manali watershed of Thrissur district, Kerala with the help of FAO- CROPWAT 8 model.

Manali river, one of the main tributary of Karuvannur river is located in Thrissur district which lies between 10°37’11’’-10°25’10’’N and 76°13’11’’-

76°25’45”E. The watershed has a drainage area of 279.11 km^2 which is confined to Kerala state only. Origin of Manali river is from Ponmudi, in the boundary of Palakkad and Thrissur districts at an elevation of +928 meters. River flows westwards up to Mundanchira and southwards up to Nenmanikkara. It then turns towards west and subsequently to south joining the Kurumali river at Palakadavu which forms Karuvanoor river (Balan 2020). The location map of the study area is shown in Fig 1.

Area under consideration for this study comes under agro-ecological unit, AEU 10: North Central Laterites. It represents midland laterite terrain with longer dry period than its southern counterpart but less than the one in the north. Climate is tropic humid monsoon type and soil is gravelly laterite clay type. The climate parameters rainfall, relative humidity, maximum and minimum temperature, wind speed and sunshine hours required for the study were collected from Kerala Agricultural University, Vellanikkara, Kerala for the period 1988-2019. Table 1 represents the monthly average climate characteristics of the study area. The soil characteristics required for the estimation of crop water requirement were available water content (mm/m) and depth of the soil (cm) and were collected from package of practices of Kerala Agricultural University. The salient crop data consisting

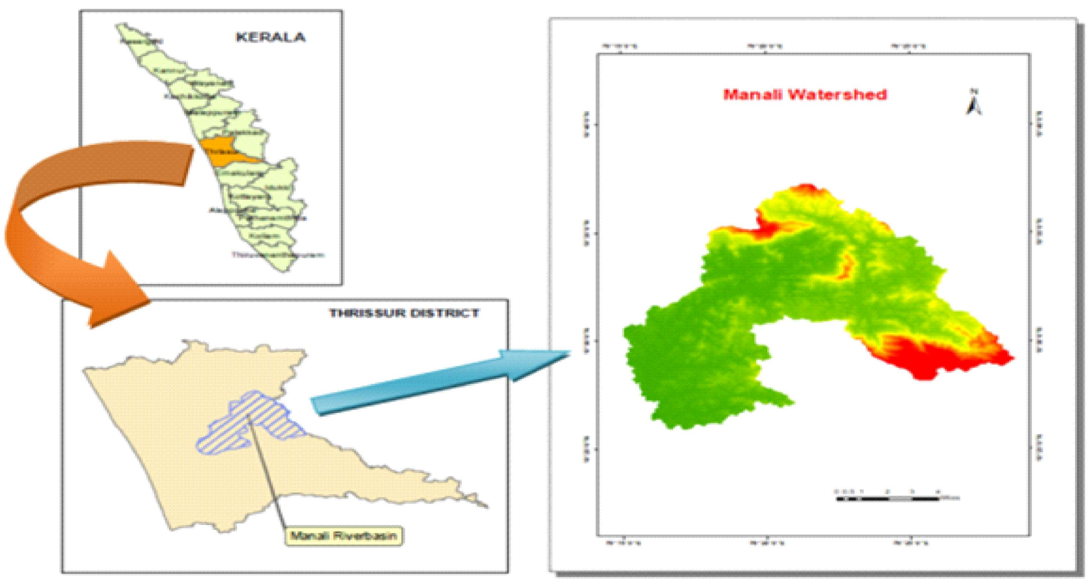

Fig 1. Location map of study area

Table 1. The average climate characteristics of Manali watershed during 1988-2018

Month	Minimum temperature (°C)	Maximum temperature (°C)	Humidity (%)	Wind velocity	Sunshine (h)	Radiation (MJ/m^2/day)	ET$_0$ (mm/day)
Jan	22.2	32.9	56	188	8.9	20.3	5.28
Feb	22.7	34.7	57	146	9.2	22.1	5.46
Mar	24.1	35.8	65	98	8.6	22.4	5.27
Apr	25	34.9	71	84	7.6	21.2	4.89
May	24.8	33.2	76	82	6.2	18.8	4.26
Jun	23.4	30	86	79	3.1	13.9	3.06
Jul	22.9	29.2	87	74	2.4	12.9	2.82
Aug	23.2	29.6	85	73	3.7	15.1	3.24
Sep	23.2	30.5	82	67	5.3	17.4	3.68
Oct	23.1	31.3	81	65	5.6	16.9	3.6
Nov	23.1	31.7	71	111	6.5	17.2	3.91
Dec	22.6	31.8	62	186	7.3	18.4	4.7
Average	23.4	32.1	73	104	6.3	18	4.18

Table 2. Crop and soil data used in the study

Crop	Planting date	Harvesting date	Critical depletion fraction	Rooting depth (cm)	Crop growth period (days)			
					Initial crop	Development	Mid-season	Late season
Banana (rainfed)	4 Aug	31 May	0.48	90	60	60	75	45
Banana (irrigated)	4 April	27 Feb	0.48	60	90	165	45	30
Soil type			Laterite					
Total available soil moisture			200 mm/m					
Maximum rain infiltration rate			40 mm/day					
Maximum rooting depth			900 cm					

of rooting depth, critical depletion, yield response factor and crop coefficient of banana were collected from FAO website and package of practices of Kerala Agricultural University (Table 2).

METHODOLOGY

CROPWAT 8.0 model description

The Land and Water Development division of FAO developed a decision support tool named CROPWAT 8 to estimate reference crop evapotranspiration, crop water requirement (CWR), irrigation requirement (IR) and irrigation scheduling. Irrigation scheduling for different management conditions and calculation of scheme water supply for different crop patterns are also possible in this software. The CROPWAT incorporates the procedure for computation of ET_0, ET_C, IR and irrigation schedule and allows simulation under various climate, crop and soil conditions.

Computation of ET_0

The reference crop evapotranspiration (ET_0) was calculated by Penman-Monteith equation in the decision support software CROPWAT 8. The equation is as follows:

$$ET_o = \frac{0.408\Delta(R_n - G) + \Upsilon\frac{900}{T+273}u_2\,(e_s - e_a)}{\Delta + \Upsilon(1+0.34u_2)}$$

where ET_0= Reference evapotranspiration (mm/day), R_n= Net radiation at the crop surface (MJ/m^2/day), G= Soil heat flux density (MJ/m^2/day), T= Air temperature at 2 m height (°C), u_2= Wind speed at 2 m height (m/s), e_s= Saturation vapour pressure (kPa), e_a= Actual vapour pressure (kPa), e_s-e_a= Saturation vapour pressure deficit (kPa), Δ = Slope of vapour pressure curve (kPa/°C), γ= Psychrometric constant (kPa/°C)

Computation of ETc

Crop water requirement is represented as ET_C in mm/day in this software. It is defined as the depth of water needed to meet the water loss through evapotranspiration of a disease free crop, growing in fields under non-restricting soil conditions including soil water and fertility and achieving full production potential under the given growing environment (Doorenbos and Pruitt 1977). Hence the calculation of ET_C is derived from ET_0 based on equation:

$$ET_C = K_C \times ET_0$$

where K_C= Crop coefficient

Computation of effective rainfall

USDA-SCS method was used for estimating effective rainfall. The equation used for calculating the effective rainfall is as follows:

Peff= Ptot (125-0.2*Ptot)/125 for Ptot <250mm
Peff= 125 + 0.1 Ptot for Ptot >250 mm

where Peff = Effective rainfall (mm), Ptot= Total rainfall (mm)

Computation of IR

The CROPWAT model calculated the daily water balance of the root zone as the root zone depletion at the day's end by the equation:

$$Dr,i = Dr,i\text{-}1 - (P - ROi) - Ii - CRi + ETci + Dpi$$

where Dr,i= Root zone depletion at the day's end i (mm), Dr,i-1= Water content in the root zone at the previous day's end (mm), Pi- Precipitation on day i (mm), ROi= Surface soil runoff on day i (mm), Ii= Net irrigation depth on day i which infiltrates the soil (mm), Cri= Capillary rise from the groundwater table on day i (mm), ETci= Crop evapotranspiration on day i (mm), Dpi= Lost water of the root zone on day i (mm)

Net irrigation requirement

Net irrigation requirement was estimated as:

$$NIR = ETc - Peff$$

Computation of irrigation scheduling

Irrigation scheduling is the process of deciding the time of application and quantity of water to be applied for the growth of crops without compensating the yield. Irrigation scheduling was done based on the climate, soil and crop data collected locally from the study area. The irrigation scheduling was made with the help of CROPWAT 8 model. The scheduling was based on the criteria ie irrigate at 100 per cent critical depletion and irrigation application was refill soil up to field capacity. The different administration conditions and water supply plans can also be developed from this model.

RESULTS and DISCUSSION

Banana is one of the major crops in Manali watershed of Thrissur district, Kerala and is cultivated in two seasons. It is cultivated as rainfed and irrigated crop. The crop water requirements of banana for two seasons were found out using the model.

Reference crop evapotranspiration (ET_0)

The reference crop evapotranspiration (ET_0) was estimated by FAO Penman-Monteith method (Surendran et al 2015). ET_0 ranged from 2.82 to 5.46 mm/day. The maximum was found to be in the month of February (5.46 mm/day) and the minimum in the month of July (2.82 mm/day). It was found that ET_0 was high during summer and low during monsoon season. The monthly variation of ET_0 is shown in Fig 2.

Crop water requirement (ETc) of banana (rainfed and irrigated)

Depth of water required to compensate the ET losses is coined as crop water requirement (ETc). ETc varies with soil, crop and climate. In each growth stage also crop water requirement differs. Crop water requirement of rainfed and irrigated banana is shown in Tables 3 and 4 respectively. The crop water requirement of rainfed and irrigated banana was found to be 1,063.5 and 1,144.5 mm/dec respectively.

Effective rainfall

Effective rainfall based on USDA-SCS method ranged from 1.9 to 192.2 mm. It was lowest during the month of January and highest during June. The monthly variation of effective rainfall is shown in Fig 3.

Irrigation requirement of banana (rainfed and irrigated)

Irrigation requirement of rainfed and irrigated banana crop was found to be 499.8 and 700.1 mm/dec respectively. In the first season (rainfed season) the irrigation requirement was low whereas it was high during the second season (irrigated season) as shown

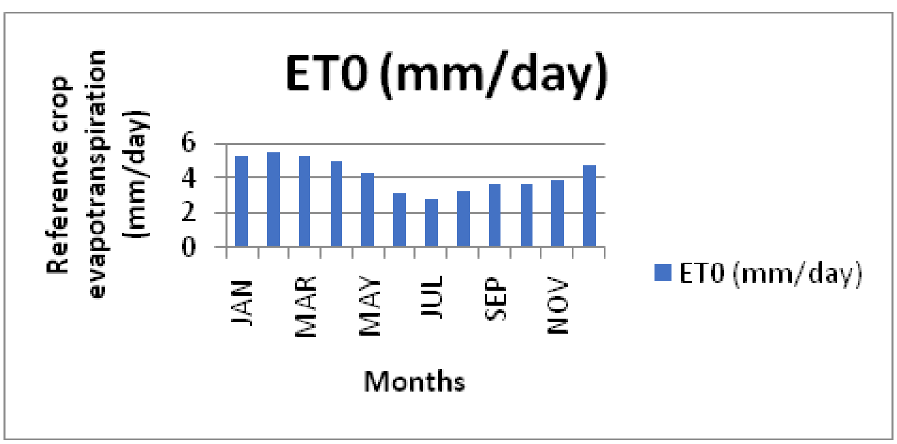

Fig 2. Monthly variation of reference crop evapotranspiration (ETo)

Table 3. Crop water requirement of banana (rainfed)

Month	Decade	Stage	Kc coefficient	ETc (mm/day)	ETc (mm/dec)	Effective rain (mm/dec)	Irrigation requirement (mm/dec)
Apr	1	Initial	0.5	2.47	17.3	12.2	8.6
Apr	2	Initial	0.5	2.44	24.4	27.6	0
Apr	3	Initial	0.5	2.41	24.1	24.5	0
May	1	Initial	0.5	2.29	22.9	42.9	0
May	2	Initial	0.5	2.14	21.4	43.8	0
May	3	Initial	0.5	1.99	21.8	51.3	0
Jun	1	Initial	0.5	1.66	16.6	60.9	0
Jun	2	Initial	0.5	1.46	14.6	65.8	0
Jun	3	Initial	0.5	1.48	14.8	65.4	0
Jul	1	Development	0.51	1.5	15	62.3	0
Jul	2	Development	0.55	1.5	15	64.9	0
Jul	3	Development	0.58	1.63	18	62.4	0
Aug	1	Development	0.62	1.87	18.7	58.2	0
Aug	2	Development	0.65	2.11	21.1	54.3	0
Aug	3	Development	0.69	2.38	26.2	54.6	0
Sep	1	Development	0.73	2.54	25.4	52.9	0
Sep	2	Development	0.76	2.87	28.7	51	0
Sep	3	Development	0.79	2.99	29.9	48.7	0
Oct	1	Development	0.83	3.04	30.4	53	0
Oct	2	Development	0.86	3.07	30.7	52.3	0
Oct	3	Development	0.9	3.21	35.4	49.8	0
Nov	1	Development	0.94	3.41	34.1	39	0
Nov	2	Development	0.97	3.81	38.1	22.7	15.4
Nov	3	Development	1	4.16	41.6	11.8	29.8
Dec	1	Development	1.04	4.62	46.2	9	37.3
Dec	2	Mid	1.07	4.98	49.8	4.3	45.4
Dec	3	Mid	1.07	5.27	58	2.4	55.6
Jan	1	Mid	1.07	5.52	55.2	0.1	55.1
Jan	2	Mid	1.07	5.6	56	1.5	54.5
Jan	3	Late	1.07	5.75	63.2	0.3	62.9
Feb	1	Late	1.04	5.74	57.4	1.9	55.5
Feb	2	Late	1.01	5.53	55.3	4.4	50.9
Feb	3	Late	0.98	5.2	36.4	6.7	28.7
					1,063.5	1,163	499.8

in Figs 4 and 5. It could be due to the availability of monsoon rainfall during the rainfed season.

Irrigation scheduling of banana (rainfed and irrigated)

The total gross and total net irrigation was 595.3 and 416.7 mm respectively for rainfed season banana (Table 5) whereas it was 962 and 673.4 mm respectively for irrigated season (Table 6). The scheduling was based on the criteria ie irrigate at 100 per cent critical depletion and irrigation application was refill soil up to field capacity. There were five irrigation schedules for rainfed banana and nine for irrigated banana.

NIR (net irrigation requirement) is the amount of water that must be supplied to enhance the growth of crops. NIR is greatly influenced by the cropping pattern and climate of the area under consideration. NIR is the difference between crop water requirement and effective rainfall. Crop water requirement includes ET and all other application losses.

The graphical representation of irrigation scheduling of rainfed and irrigated banana is shown in Figs 6 and 7 respectively. Here the days after planting (x-axis) is plotted against soil water retention (y-axis). TAM is the total available moisture or the total amount of water available to the crop. RAM is the readily

Table 4. Crop water requirement of banana (irrigated)

Month	Decade	Stage	Kc coefficient	ETc (mm/day)	ETc (mm/dec)	Effective rain (mm/dec)	Irrigation requirement (mm/dec)
Aug	1	Initial	1	3.04	21.3	40.7	0
Aug	2	Initial	1	3.22	32.2	54.3	0
Aug	3	Initial	1	3.45	38	54.6	0
Sep	1	Initial	1	3.5	35	52.9	0
Sep	2	Initial	1	3.77	37.7	51	0
Sep	3	Initial	1	3.77	37.7	48.7	0
Oct	1	Development	1.01	3.7	37	53	0
Oct	2	Development	1.04	3.69	36.9	52.3	0
Oct	3	Development	1.06	3.81	41.9	49.8	0
Nov	1	Development	1.09	3.98	39.8	39	0.9
Nov	2	Development	1.12	4.4	44	22.7	21.3
Nov	3	Development	1.15	4.76	47.6	11.8	35.7
Dec	1	Mid	1.16	5.17	51.7	9	42.8
Dec	2	Mid	1.16	5.42	54.2	4.3	49.9
Dec	3	Mid	1.16	5.74	63.1	2.4	60.7
Jan	1	Mid	1.16	6.01	60.1	0.1	60
Jan	2	Mid	1.16	6.1	61	1.5	59.5
Jan	3	Mid	1.16	6.27	69	0.3	68.7
Feb	1	Mid	1.16	6.41	64.1	1.9	62.3
Feb	2	Late	1.15	6.31	63.1	4.4	58.7
Feb	3	Late	1.1	5.88	47.1	7.7	39.4
Mar	1	Late	1.05	5.65	56.5	4.2	52.3
Mar	2	Late	1	5.3	53	13	40.1
Mar	3	Late	0.94	4.78	52.5	4.6	47.9
					1,144.5	584.1	700.1

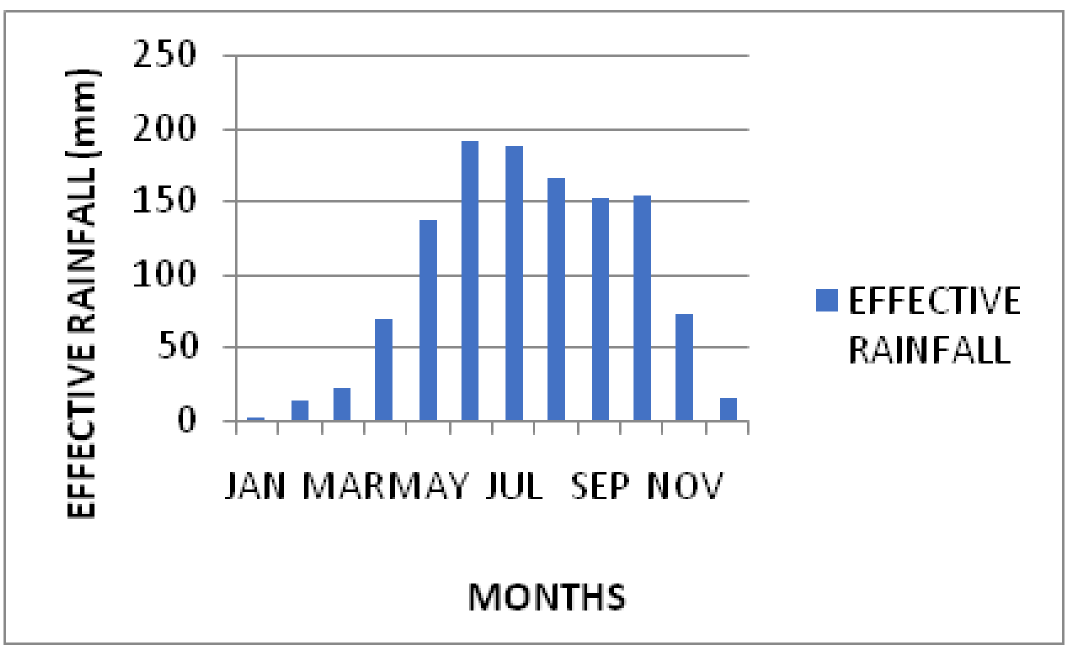

Fig 3. Effective rainfall

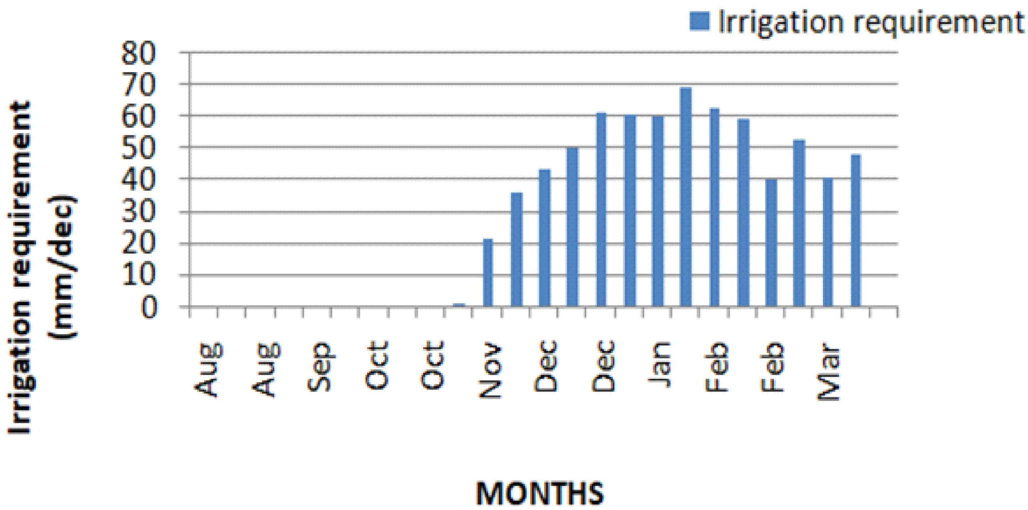

Fig 4. Irrigation requirement of banana (irrigated)

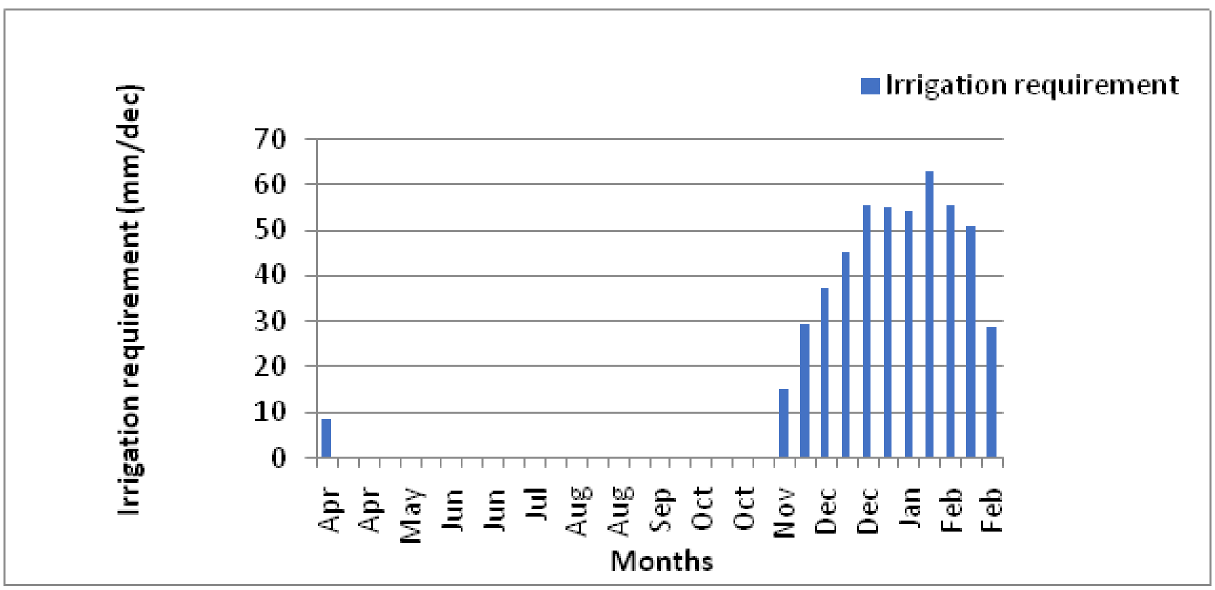

Fig 5. Irrigation requirement of banana (rainfed)

Table 5. Irrigation scheduling of banana (rainfed)

Date	Day	Stage	Rain (mm)	Depletion (%)	Net irrigation (mm)	Deficit (mm)	Loss (mm)	Gross irrigation (mm)
10 Dec	251	Development	1.6	46	82.3	0	0	117.6
27 Dec	268	Mid	1.4	45	81.6	0	0	116.6
12 Jan	284	Mid	0	48	86.4	0	0	123.5
27 Jan	299	Mid	0	46	83.1	0	0	118.7
11 Feb	314	End	0.9	46	83.3	0	0	119.0
27 Feb	End	End	0	39	-	-	-	-

Table 6. Irrigation scheduling of banana (Irrigated)

Date	Day	Stage	Rain (mm)	Depletion (%)	Net irrigation (mm)	Deficit (mm)	Loss (mm)	Gross irrigation (mm)
6 Dec	125	Mid	0.7	46	83.7	0	0	119.5
23 Dec	142	Mid	0.1	47	84.2	0	0	120.2
7 Jan	157	Mid	0	47	85.0	0	0	121.5
21 Jan	171	Mid	0	47	83.8	0	0	119.7
4 Feb	185	Mid	0	48	86.9	0	0	124.1
18 Feb	199	End	2.3	47	84.1	0	0	120.2
6 Mar	215	End	0.2	46	83.5	0	0	119.3
25 Mar	234	End	0	46	82.2	0	0	117.4
31 Mar	End	End	0.8	11	-	-	-	-

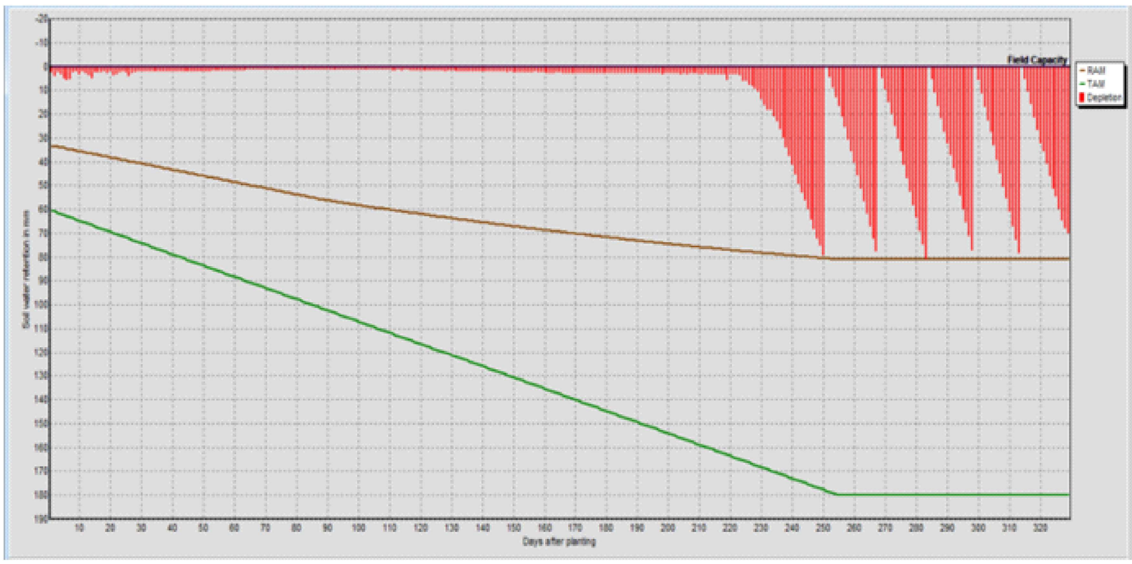

Fig 6. Irrigation scheduling of banana (rainfed)

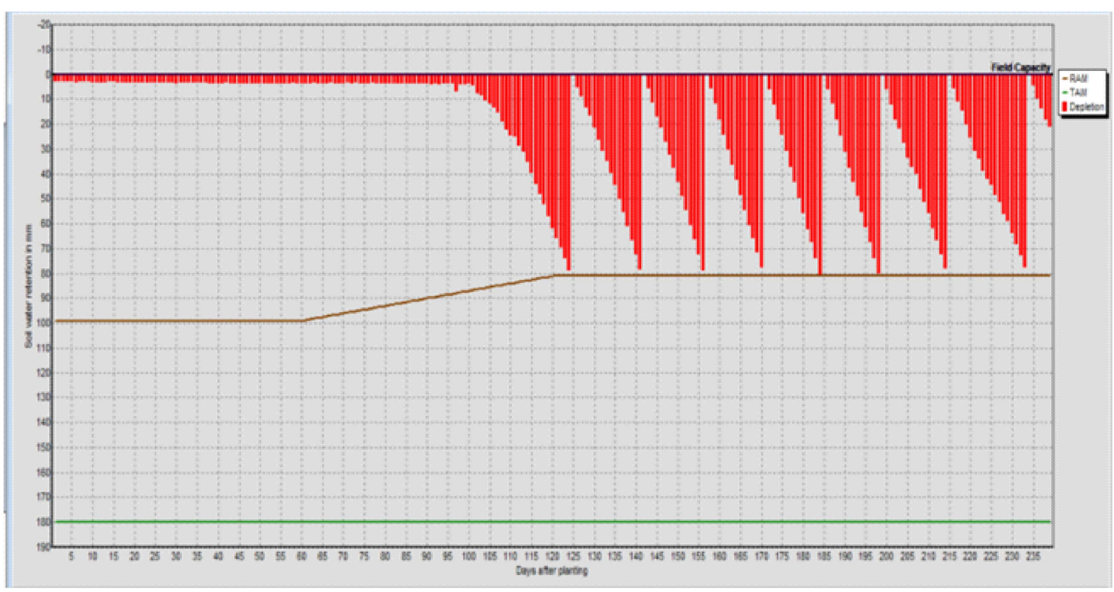

Fig 7. Irrigation scheduling of banana (irrigated)

available water or the portion of TAM that the plant can get from the root zone without facing water stress (Some et al 2006).

For rainfed banana, the first irrigation was given on 251[th] day after planting with 82.3 mm of net irrigation. After this subsequent irrigations were given after 268, 284, 299 and 314 days after sowing with 81.6, 86.4, 83.1 and 83.3 mm of net irrigation respectively. Considering an efficiency of 70 per cent during each irrigation, gross irrigation required was 117.6, 116.6, 123.5, 118.7 and 119.0 mm respectively.

For irrigated banana the first irrigation was given on 125[th] day after planting with 83.7 mm of net irrigation. After this subsequent irrigations were given after 142, 157, 171, 185, 199, 215 and 234 days with 84.2, 85, 83.8, 86.9, 84.1, 83.5 and 82.2 mm of net irrigation respectively. Considering an efficiency of 70 per cent during each irrigation, the gross irrigation required was 119.5, 120.2, 121.5, 119.7, 124.1, 120.2, 119.3 and 117.4 mm respectively.

CONCLUSION

The quantity of available water is decreasing day by day. There will be an increased chance of water scarcity in the Manali watershed, Kerala in the coming years. In this scenario, it is necessary to find out the crop water requirement by considering the climatic factors, soil conditions and crop type and thereby water can be applied in proper quantity and at the proper time. Hence the climatic and soil conditions based on agro-ecological units were considered for this study. In Manali watershed, banana is one of the major crops and is cultivated in two seasons; one during rainfed and second in irrigated season. The crop water requirement and irrigation scheduling of banana was calculated using CROPWAT 8 model. The ET_0 values ranged from 2.82 to 5.46 mm/day in this study. The crop water requirement of rainfed and irrigated banana was found to be 1,063.5 and 1,144.5 mm/dec respectively. The effective rainfall based on USDA-SCS method ranged from 1.9 to 192.2 mm. Irrigation requirement of rainfed and irrigated banana crop was found to be 499.8 and 700.1 mm/dec respectively. The variation in crop water requirement depends on soil, crop, crop stage and climatic conditions. Evapotranspiration was found high during the second season and hence the crop water requirement was also high during that season. Because of the low availability of rainfall during second season irrigation was necessary. Irrigation schedules of banana for both the seasons were also arrived at. As per recommendations of this study, the amount of water supplied as per the usual recommendations are needed to be revised. This will increase the water use efficiency and productivity of banana in Manali watershed. The results of this study can be used for water resources planning in the watershed.

REFERENCES

Allen RG, Pereira LS, Raes D and Smith M 1998. Crop evapotranspiration: guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper #56, Rome, Italy.

Balan P 2020. Water conservation measures and cropping pattern for a watershed using geospatial techniques and SWAT modelling. Department of Irrigation and Drainage Engineering, Kelappaji College of Agricultural Engineering and Technology, Tavanur, Malappuram, Kerala, India.

Doorenbos J and Pruitt WO 1977. Guidelines for predicting crop water requirements. Irrigation and Drainage Paper #24, FAO, Rome, 144p.

Some L, Dembele Y, Ouedraogo M, Some BM, Kambire FL and Sangare S 2006. Analysis of crop water use and soil water balance in Burkina Faso using CROPWAT. University of Pretoria, Pretoria, South Africa.

Surendran U, Sandeep O, George M and Joseph EJ 2013. A novel technique of magnetic treatment of saline and hard water for irrigation and its impact on cow pea growth and water properties. International Journal of Agriculture, Environment and Biotechnology **6(1):** 85-92.

Surendran U, Sushanth CM, Mammen G and Joseph EJ 2015. Modeling the crop water requirement using FAO-CROPWAT and assessment of water resources for sustainable water resource management: a case study in Palakkad district of humid tropical Kerala, India. Aquatic Procedia **4:** 1211-1219.

Varadan KM 1996. Water module for upland crops of Kerala. Centre for Water Resources Development and Management, Kozhikode, Kerala, India, 59p