Research article

Estimation of Crop Water Requirements and Irrigation Scheduling for Major Crops Grown in India's North-Eastern Region

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Abstract

The water demand of some agricultural crops grown in Assam was assessed in this research. To estimate the crop water requirements of potato, chili, and brinjal, the FAO-CROPWAT model was used. The climatic parameters like rainfall, solar radiation, wind speed, sun hours, relative humidity, minimum and maximum temperature were collected for 30 years from the Indian Meteorological Department (IMD) to estimate the crop water requirement (CWR). The reference evapotranspiration (ET_o) was computed by using the Food and Agriculture Organization (FAO)-recommended Penman-Monteith method and was found to vary from 1.84 mm/day to 4.49 mm/day. The calculated ET_o was further used to compute the CWR, the net irrigation requirement (NIR), and the gross irrigation requirement (GIR) to plan for irrigation application during the growing stages of the selected crops. The total CWR of potato, chili, and brinjal was estimated to be 260.6 mm, 262.1 mm, and 274.2 mm, respectively, and the total NIR of potato, chili, and brinjal sowed on the 1st of October was found to be 162.8 mm, 149.0 mm, and 167.2 mm, respectively, with an irrigation efficiency of 70%. In December, the CWR and NIR of potato and brinjal were found to be the highest. The month with the least effective rainfall (8.5 mm) was December. The findings of the study showed that efficient irrigation water management and irrigation scheduling can be achieved by using the CROPWAT model to maximize crop yield and minimize crop water stress.

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1. Introduction

Agriculture is one of the most important sources of livelihood and its rapid expansion does not only help in ensuring the security of food and nutrition but also in achieving self-sufficiency for people. It also aims to achieve a balanced distribution of income and wealth in rural areas, eliminating poverty and improving living standards. Agriculture's expansion has a greatest cascading effect on other sectors, resulting in benefits being disseminated over the whole economy and the broadest percentage of the population. Increased water demands due to fast population growth have prompted the expansion of irrigation and industrial output to meet basic human requirements [1, 2]. Insufficient precipitation becomes the primary goal for the application of irrigation to maintain and meet agricultural evapotranspiration (ET) [3, 4]. More than 75 % population of the state of Assam lives in rural areas, and due to certain factors, the direct use of river water is limited. Due to the lack of location-specific crop type information and irrigation scheduling for different crops, only a few research studies have paid attention to irrigation water requirements and irrigation efficiency in Assam. Improper use of irrigation water can adversely affect crop yields in the region. Because water is such an important element for crop production, it has become a necessity to plan and distribute this limited resource efficiently [5, 6]. Many methods are employed for the estimation of evapotranspiration. Since accurate measurement of evapotranspiration becomes strenuous under field conditions, potential evapotranspiration is often predicted on the basis of climatological data. Empirical formulas like the Blaney-Criddle method use the monthly percentage of total daylight hours in the year and the mean monthly temperature. The Thornwaite method is based on the exponential relationship between mean monthly temperature and consumptive use, and the Hargreaves method is based on the relationship between potential evapotranspiration, average daily temperature, and incident solar radiation only [7]. Since the Penman-Monteith method combines the energy balance method with the mass transfer method and incorporates the climatic effect on crop factors to compute the evapotranspiration, it is one of the most widely used methods [8-10]. Smith's CROPWAT simulations [11] make use of the Penman-Monteith method for estimating reference evapotranspiration, which is commonly employed to achieve water use efficiency. It calculates the actual evapotranspiration (ET_c) of a crop by estimating ET_o [2, 12]. Gross irrigation need is also estimated by combining climate, crop, and soil data, and enables the generation of irrigation recommendations, irrigation schedule planning under variable water supply situations, and yield reduction under varied conditions [1, 5, 8, 13]. Vegetables from all over the world, including both tropical and temperate varieties, are cultivated in the study area. Therefore, the objective of the study was to determine the crop water demand and temporal change of ET_c with respect to the water requirements of some of the major horticultural crops grown in the region using a CROPWAT 8.0 decision-making tool. An attempt was also made to estimate the irrigation frequency by planning the irrigation schedule.

2. Materials and Methods

2.1 Description of the study area

The study focuses on Assam, one of the eight states in the North-Eastern region of India (Figure 1), located at latitude 26.24 N and longitude 92.53 E. It covers a geographical area of 78,438 km^2, encompassing three of India’s six physiographic divisions known as the Northern Plains (Brahmaputra plain), the Northern Himalayas (Eastern Hills), and the Deccan plateau (Karbi Anglong district). As per the 2011 census of India, the region had a record of 3.12 million people, with a population density of 398 people per km^2. Since the Brahmaputra River flows through Assam, the region experiences cold and wet climates for the majority of the year. In 2020, the actual rainfall level for Assam was 2,175.96 mm and the average temperature of the region was between 8°C (during winter) and 32°C (during summer). Agriculture employs roughly 53% of the rural population of Assam, making it essentially an 'agrarian economy' with 0.90 million cultivators and 0.20 million agricultural laborers, respectively. According to the 2010-2011 Agricultural Census, the state had 2.72 million operational holdings covering around 2.99 million hectares.

2.2 CROPWAT 8.0 model description

Model Description FAO's Land and Water Development Division in Italy, with the help of Southampton University's Institute of Irrigation and Development Studies and Egypt's National Water Research Center, developed a decision-making tool called CROPWAT 8.0 to help in planning the best scheduling time for irrigation of crops [14]. To produce irrigation schedules under varied management conditions, the model performs calculations for ET_o, ET_c, and NIR. It enables the generation of irrigation recommendations, the scheduling of irrigation schedules, and the evaluation of productivity using soil, climatic, and crop data [8, 11-17]. CROPWAT 8.0 can also be used to assess farmers' irrigation methods and forecast crop performance in both wet and dry circumstances.

2.3 Data collection

2.3.1 Climatic data

The daily climatic data (1990-2020) such as rainfall, solar radiation, minimum, maximum, and mean temperature at 2 m height, humidity, wind speed at 2 m height, and sunshine hours for the study were collected from the India Meteorological Department (IMD) [18] and adjusted to a monthly scale for analysis. The average annual wind speed, sunshine hours and annual rainfall for the study area were observed to be 1.4 m/s, 6.42 h and 2436.4 mm, respectively. The region of Assam contains two hill districts and twenty-one plain districts. The hills of the region experience a subalpine climate, whereas the plains areas enjoy hot summers and cool winters. Eighty percent of the rainfall in Assam comes from the South-West monsoon, which starts in June and continues till September. Figure 2 and Figure 3 represent the month-wise solar radiation, sun hours, minimum and maximum temperature profiles of the study area for the period of 30 years (1990 to 2020).

2.3.2 Soil data

Alluvial soils, hill soils, piedmont soils, and lateritic soils constitute the major soil categories found in Assam. Extremely rich and deep alluvial soil with fine loam to coarse loam texture has been found to be in abundance in the Brahmaputra and Barak plains. The piedmont soil zone lies in the Himalayan foothills where the soils are quite deep and loamy in texture, ranging from fine to coarse. The soil data required by the CROPWAT model, such as soil type, maximum infiltration rate, available moisture, both total and initial, rooting depth of the specific crop, and initial soil depletion level, were taken from the FAO-Irrigation and Drainage manual [19].

2.3.3 Crop data

Potato, chili, and brinjal were chosen as the study's main farmed horticulture crops. According to the Ministry of Irrigation, Government of India (1984) and FAO-Irrigation and Drainage manual, important details of crops such as crop coefficient, duration of growth stages, yield response factor, crop height, and other related facts were examined for the study region. The crop-wise area, production.

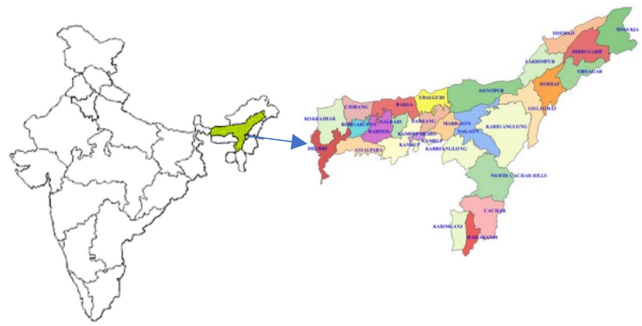

Figure 1. Location of study area (source: www.google .com)

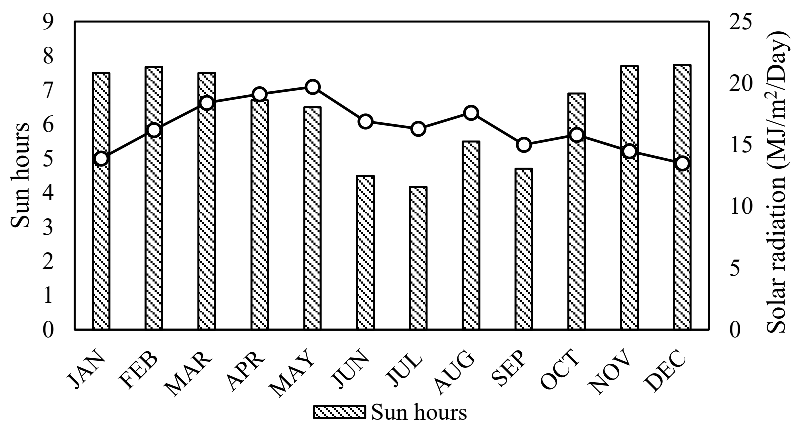

Figure 2. Month-wise average sunshine hours and solar radiation of the study area during 1990 to 2020

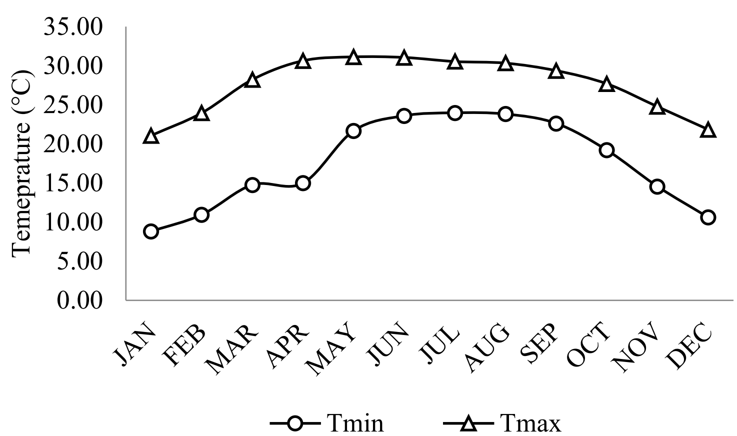

Figure 3. Month-wise average minimum and maximum temperature variation during 1990 to 2020

and average yield of the selected crops are presented in Table 1, and Table 2 contains the crop coefficient value for different crop growth stages.

Table 1. Crop-wise area, production and average yield

Crop	Area ('000 Ha)	Production ('000 MT)	Avg. yield (Kg/Ha)
Potato	103.205	773.48	7495
Chili	19.847	189.84	9565
Brinjal	17.76	286.35	16123

Table 2. Crop coefficient and growing period of potato, chili and brinjal

Crop		Potato	Chili	Brinjal	Date of sowing
Crop coefficient (K_c)	Initial	0.5	0.66	0.6	1 Oct
	Mid	1.5	0.92	1.15	1 Oct
	Final	0.75	1.12	0.80	1 Oct
Growing period (days)	Initial	25	20	30	1 Oct
	Development	30	30	40	1 Oct
	Mid-season	45	60	40	1 Oct
	Late-season	30	40	20	1 Oct
	Total growing days	130	150	130	

2.3.4 Data analysis

The daily climatic baseline data were adjusted to monthly scale and used in the CROPWAT 8.0 to determine the ET_o for the study area. The ET_o data obtained was further used to calculate the ET_c. The flow chart showing the methodology for estimation of the irrigation demand using CROPWAT model is shown in Figure 4.

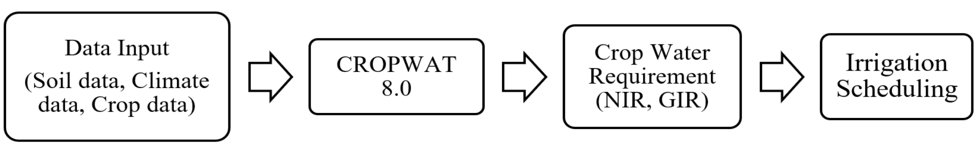

Figure 4. Flow chart for the estimation of irrigation demand and scheduling using CROPWAT model

2.4 Crop water requirement

During the crop's growing season, water lost in the soil and plants, known as evapotranspiration, must be replenished for the crop to survive. The water lost due to the evaporation and transpiration processes together constitutes the crop water requirement of the crop. The reference crop evapotranspiration was calculated using the FAO-recommended Penman-Monteith (1992) method in the CROPWAT model and the FAO Penman-Monteith model has long been widely recommended for estimating ET_o [17, 20-22]. In the absence of measured data, it has been extensively used around the world [23]. The output ET_o calculated using equation (1) was expressed in mm per day even though monthly climatic data was used as input. The output ET_o rate in mm/day represents the average daily ET_o of any given month. The daily ET_o values were further adjusted to the monthly scale for analysis (Figure 5).

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \quad (1)$$

where, ET_o = Reference Evapotranspiration [mm day^{-1}], R_n = Net radiation at the crop surface [day^{-1}], G = Soil heat flux density [MJm^2day^{-1}], T = Mean daily air temperature at 2 m height [°C], U_2 = Wind speed at 2 m height [ms^{-1}], e_s = Saturation vapour pressure [kPa], e_a = Actual vapour pressure [kPa], $e_s - e_a$ = Saturation vapour pressure deficit [kPa], Δ = Slope vapour pressure curve [kPa $°C^{-1}$], γ = Psychrometric constant [kPa $°C^{-1}$] which is considered as 0.0677 kPa $°C^{-1}$.

The crop coefficient (K_c) of the selected crops for specific growth stages and the Penman–Monteith equation were used to calculate the monthly ET_c of crops.

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

where, ET_c is the actual evapotranspiration of crops in mm and K_c is the crop coefficient at a specific growth stage.

2.5 Effective rainfall and NIR

In the CROPWAT model, the effective rainfall was estimated using the approach given by the United States Department of Agriculture Soil Conservation Service (USDA-SCA) [2]. The following equations (3) and (4) were used for estimating the monthly effective rainfall using this approach.

$$P_e = \frac{P_T(125 - 0.6P_T)}{125} \; for \; P_T \leq \frac{250}{3} \; mm \quad (3)$$

$$P_e = \frac{125}{3} + 0.1(P_T) for \; P_T \geq \frac{250}{3} \; mm \quad (4)$$

where, P_e represents the monthly effective rainfall in mm; P_T is the total monthly rainfall in mm.

The following equations (5) and (6) were used to compute the monthly NIR and GIR which includes the water losses from the irrigation system.

$$NIR = ET_c - P_e \quad (5)$$

$$GIR = \frac{NIR}{P_o} \quad (6)$$

where, P_o represents the performance of irrigation operation which depends on the characteristics of the adopted irrigation methods (70 % for surface irrigation) [13].

3. Results and Discussion

3.1 Reference evapotranspiration

The daily scale ET_o value was computed to find the monthly evapotranspiration in mm and has been presented in Figure 5. The ET_o of the region was found to be highest in April (134.70 mm) at an average ET_o rate of 4.49 mm/day, followed by May (130.90 mm) at an average ET_o rate of 4.30 mm/day. The lowest ET_o occurred in December (55.20 mm) at an average ET_o rate of 1.84 mm/day. Several climatic parameters were considered when computing the ET_o rate of any watershed area. Any change in the climatic parameters highly influences the change in the value of the estimated ET_o rate, among which solar radiation and temperature affect it the most.

3.2 Effective precipitation

The effective rainfall was lowest in December (8.5 mm), which indicates that a large quantity of irrigation water will be required to replenish the soil with moisture. During the monsoon season, the effective rainfall values were found to be satisfactory. Figure 6 represents the month-wise total and effective rainfall of the region. The month of July experienced the highest amount of effective rainfall (173.2 mm) which was followed by June (171.2 mm).

3.3 Crop water and net irrigation requirement

Table 2 represents the crop coefficient and days of growth stages of the selected crops. For total growing periods of 130, 150, and 130 days, the total CWR of potato, chili, and brinjal was estimated to be 260.6 mm, 262.1 mm, and 274.2 mm, respectively. The NIR presented in Table 3 shows the total NIR of potato, chili, and brinjal sowed on the 1st of October as 162.8 mm, 149.0 mm, and 167.2 mm, respectively. The CWR and NIR of potato and brinjal were found to be the highest in December. The high CWR was due to the absence of a sufficient amount of effective rainfall required to replenish the soil. Therefore, a higher amount of irrigation water has to be supplied to meet the irrigation demands of the crop. Also, the crop water requirement depends on the stage of its growth. It can be seen that the chili plant required the highest CWR in January. CROPWAT results confirmed the fact that ET_o value was highly influenced by the amount of effective rainfall. Thus, during the rainy season, the value of ET_o was lower in comparison to the estimated ET_o value during the dry or water deficit season. The same inference has been made by others in their research work [24]. From November to January, the overall water needs climb steadily, and then drop with the increase in effective rainfall. The difference between GIR and NIR gives the irrigation losses at the field level. Differences in crop development stages, crop coefficients, and cropping area account for the difference in monthly water demand [13, 25]. As a result, it has been considered critical to develop a strategy of water management depending on agricultural needs to obtain increased crop yields while preserving water resources.

3.4 Irrigation scheduling and gross water requirement

The irrigation scheduling strategy for potato, chili, and brinjal from the beginning of October to the middle of February was presented in Table 4. The total count of the division of irrigation applications needed for each crop throughout its stage of growth was given by scheduling data. The schedule was planned to irrigate the crops at critical moisture levels in the soil to fill them up to the field capacity. CROPWAT model did not assign any irrigation dates during October as a sufficient amount of effective water was available to meet the water demands of the crop. The peak NIR of

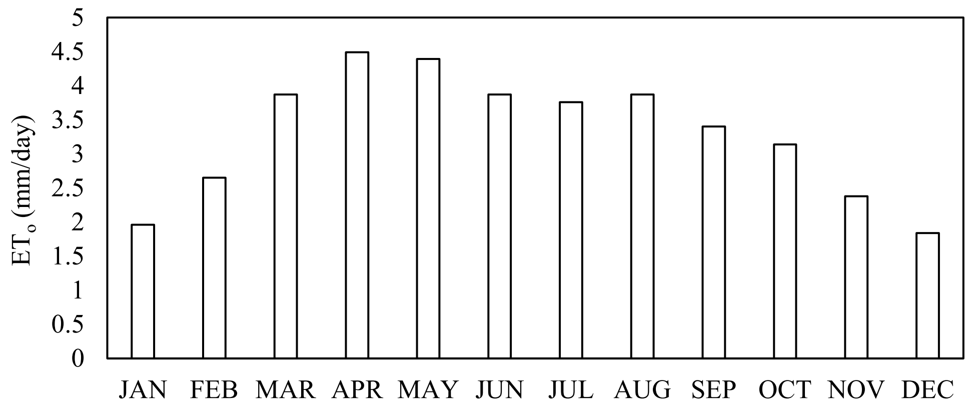

Figure 5. Estimated average daily ET_o per month from CROPWAT 8.0 during 1990 - 2020

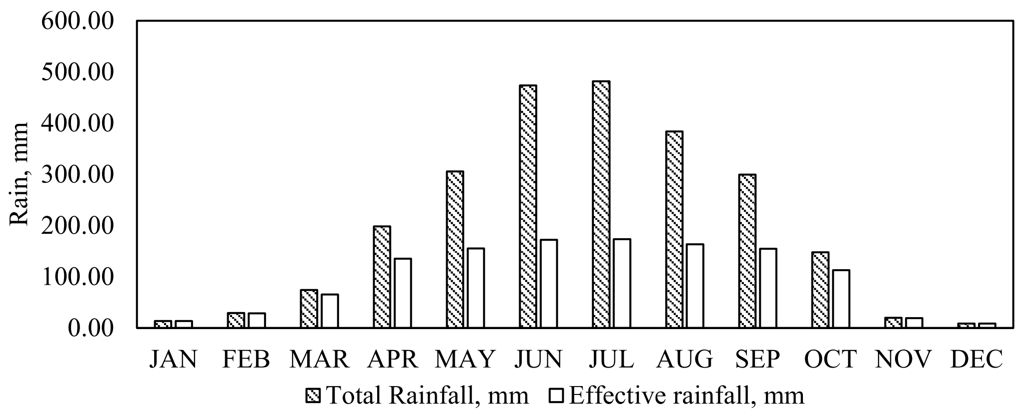

Figure 6. Month-wise average total and effective rainfall during 1990 to 2020

Table 3. Actual evapotranspiration (ET_c) and net irrigation requirement (NIR)

Month	ET_c (mm)			NIR (mm)		
	Potato	Chili	Brinjal	Potato	Chili	Brinjal
October	49.4	64.5	60.1	0	0	0
November	68.2	59.9	69.5	49	40.7	50.3
December	68.4	54.2	68.3	59.8	45.6	59.8
January	61.6	64.8	62.5	48	51.1	49
February	13	18.7	13.8	6	11.6	8.1
Total	260.6	262.1	274.2	162.8	149.0	167.2

Table 4. Irrigation scheduling plan for the crops

Crop	Date	Day	Stage	Depletion %	NIR, mm	GIR, mm	Flow, l/s/ha
Potato	16-Nov	47	Dev	31	24.0	34.3	0.08
	27-Nov	58	Mid	30	25.3	36.1	0.38
	10-Dec	71	Mid	33	27.4	39.2	0.35
	24-Dec	85	Mid	31	26.4	37.7	0.31
	8-Jan	100	Mid	32	26.7	38.2	0.29
	6-Feb	129	End	50	42.1	60.1	0.24
	7-Feb	End	End	0			
Chili	6-Oct	6	Init	20	08.5	12.2	0.24
	11-Oct	11	Init	22	10.6	15.2	0.35
	17-Nov	48	Dev	27	26.3	37.5	0.12
	8-Dec	69	Mid	32	35.3	50.5	0.28
	31-Dec	92	Mid	31	34.3	49.0	0.25
	31-Jan	123	End	45	50.8	72.6	0.27
	7-Feb	End	End	8			
Brinjal	12-Oct	12	Init	23	11.6	16.5	0.16
	15-Nov	46	Dev	27	25.8	36.9	0.13
	30-Nov	61	Mid	30	33.9	48.4	0.37
	18-Dec	79	Mid	31	34.9	49.8	0.32
	6-Jan	98	Mid	32	35.7	51.0	0.31
	7-Feb	End	End	40			

where, Dev = Development stage, Mid = Middle stage, End = Ending stage and Init = Initial stage

potato was observed in the mid-season stage (105.8 mm) followed by the end-stage (42.1 mm). Similarly, the mid-season growth stage gave the highest value of GIR (151.2 mm) for potato. However, both chili and brinjal required lesser NIR in comparison to potato with only 63 mm and 93 mm, respectively, during the mid-stage of growth. The GIR was also found to be 99.5 mm and 148.8 mm during the mid-stage of growth for chili and brinjal, respectively. Effective water balancing and knowledge about the rainwater quantity and its availability for crop irrigation can save and conserve irrigation water. The irrigation schedule plan will provide the best way to efficiently utilize irrigation water and increase the water yield at the same time.

4. Conclusions

The CWR, NIR, and GIR of potato, chili, and brinjal were estimated using CROPWAT 8.0 for Assam. The model was also used for planning the irrigation for the crops sown on the 1st of October. The findings obtained from this study can be used to adopt water-saving practices by scheduling irrigation and effective use of water during the water deficit period. Also, using this knowledge, a complete plan of irrigation scheduling can be developed to estimate irrigation demand for the other crops grown in the region to achieve a higher yield of productivity.

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