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Indian Journal of Hill Farming

June 2023,Volume 36, Issue 1, Page 114-121

Evaluation of crop irrigation requirement of French bean (*Phaseolus vulgaris* L.) under varying meteorological conditions in Imphal West district of Manipur, northeast India

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ARTICLE INFO

Article history:
Received: 22 September, 2022
Revision: 20 January, 2023
Accepted: 27 April, 2023

Key words: *Reference Evapotranspiration, Crop Coefficient, Crop Evapotranspiration, Effective Rainfall, Crop Irrigation Requirement*

DOI: 10.56678/iahf-2023.36.01.15

ABSTRACT

The purpose of this study was to evaluate the crop irrigation requirement of French bean (*Phaseolus vulgaris L.*) under varying meteorological conditions in the Imphal West district of Manipur, northeast India. The total reference evapotranspiration (ET_o) during 'Normal', 'Dry' and 'Wet' Years are estimated at 289, 300 and 285 mm, respectively. The crop coefficient (K_c) of French bean values ranges from 0.50 to 1.09 during 'Normal' Year, while K_c values ranges from 0.50 to 1.05 during 'Dry' Year and K_c values vary from 0.05 to 1.08 during 'Wet' Year. The effective rainfall is calculated at 164.3, 106.2 and 311.4 mm during 'Normal', 'Dry' and 'Wet' Years, respectively. The crop irrigation requirement (CIR) of French bean is estimated at 134.4 mm during 'Normal' Year; on the contrary, CIR of French bean during 'Dry' Year is calculated at 161.8 mm and 88.7 mm during 'Wet' Year, respectively. Thus this study will helped for successful water management for sustainable crop production.

1. Introduction

With the growing demand for vegetables in valley districts of Manipur such as Imphal West, Imphal East, Bishnupur and Thoubal, Manipur has managed to establish a significant presence in the vegetable market. In fact, in recent times, as traditional rice farming is no longer profitable, many farmers made paradigm shift from growing rice to growing vegetables in a sole pursuit of reaping maximum profit in lesser time. Recognition to the initiative of changing from rice to vegetable farming, the farmers of the Manipur state are hankering to reap maximum profits from vegetable avenues. The valley areas of Manipur are geographically suitable for the development of the vegetable sector due to prevailing soil and agro-climatic conditions which are conducive for vegetable farming. The state of Manipur is endowed with sufficient agricultural lands for growing vegetables particularly in the foothills which are relatively fertile. However, due to inadequate irrigation facilities, state agriculture is highly dependent on the hang-up of the monsoon. It is often subjected to uncertain weather conditions, causing large fluctuations in achieving satisfactory production levels. Vegetable crops like capsicum, cucumber, French bean, tomato, etc., are short- duration crops and offer a better value per unit of area compared to cereal crops such as rice, thus offering higher economic returns to small marginal farmers in Manipur who have adopted vegetable cultivation. In addition, it is also a source of intensive employment due to its nature of work participation

In the past 50 years, irrigated farming has developed on a global scale with the increase in irrigated areas and the withdrawal of water. Presently, in excess of 80% of the water consumed is intended for irrigation (Döll and Siebert, 2002). Crop irrigation requirements will be considerably exaggerated by local climate differs. Information on crop and irrigation water requirements change with the changes persuaded by irrigation in the evapotranspiration requirement may be of immense importance in upcoming agricultural water management (Han

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et al., 2013). Understanding the irrigation requirements of diverse crops is essential to plan irrigation management on farms. Reliable estimates of water requirements require information on the crop environment, such as climate and the physiological behaviour of vegetation (Saha, 2011). The crop irrigation requirement is the subtraction of effective rainfall from the crop evapotranspiration. Evaluation of crop evapotranspiration (ETc) from climatic parameters offers criteria for irrigation management.

French bean (*Phaseolus vulgaris* L.) is a very popular culinary crop usually grown in foothill areas of Imphal West district, Manipur. Due to erratic rainfall, uneven distribution of rainfall patterns, and other biotic stress on the crop, the targeted average yields of French bean could not be achieved as such. In such scenario, the agricultural production through efficient water management technology is necessary for agricultural development, in addition it aids in improving the rural economy through economic returns and the quality of life. Considering the significant potential of vegetable production and the prospect of growing vegetables to improve the overall economy of the state, the present study was undertaken with the primary objective to analyze the crop water requirement of French bean growing in the foothill areas of Imphal West district, Manipur.

2. Material and Methods

2.1 Study Area

The study was carried out in valley districts of Manipur, northeast India. The geographical location of the observation unit is 24°49'36" N latitude and 93°55'28" E longitude at Experimental Farm, Indian Council of Agricultural Research Complex for North East Hill Region, Manipur Centre, Imphal, Lamphelpat, Manipur. The elevation of thestudy site is at 777 m (Above Mean Sea level). The average annual rainfall of the study area is 1449 mm, which is obtained from ICAR Manipur Centre and the rainy monsoon season expands from the beginning of May to the end of October. Rainfed agriculture is widely practiced for crop production in almost the entire state of Manipur.

2.2 Data Collection

The daily meteorological data like rainfall, maximum temperature, minimum temperature, maximum relative humidity, minimum relative humidity, sunshine, wind speed during the 1954-2018 period and crop calendar were collected from ICAR Research Complex for NEH Region, Manipur Centre, Imphal, Lamphelpat, Manipur.

2.3 Climate of Study Area

The climate of the study area is subtropical. The study area receives the rainfall from South-East monsoon with a mean annual rainfall of 1449 mm with a standard deviation of 284 mm for the last 64 years (1954-2018). January is the coldest month with a mean monthly temperature varying from 1.7°C to 7.4°C. The monthly average maximum, minimum temperature and rainfall during the 1954-2018 period are given in Fig. 1.The maximum monthly temperature was recorded in August with an average of 27.9°C. The monthly average maximum temperature of 64 years (1954-2018) changing between 16.8°C and 32.8°C, whereas the monthly average minimum temperature was fluctuating between 1.7°C and 23.0°C. The average relative humidity of 34 years (1985-2018) was 75.2% and varying between 14% and 100%. The weekly average wind speed was 2.9 km/h and ranging between 0 to 32.3 km/h during 23 years (1996-2018). The regular bright sunshine hours were 5.9 h and varying between 0 to 12.3 h during the 1985-2018 period.

Table 3.1. Details of the meteorological data for the study area

Sl. No.	Data Type	Time Scale	Year
1.	Rainfall	Daily	1954-2018
2.	Maximum Temperature	Daily	1954-2018
3.	Minimum Temperature	Daily	1954-2018
4.	Maximum Relative Humidity	Daily	1985-2018
5.	Minimum Relative Humidity	Daily	1985-2018
6.	Sunshine	Daily	1985-2018
7.	Wind Speed	Daily	1996-2018
8.	Crop Calendar	Seasonal	

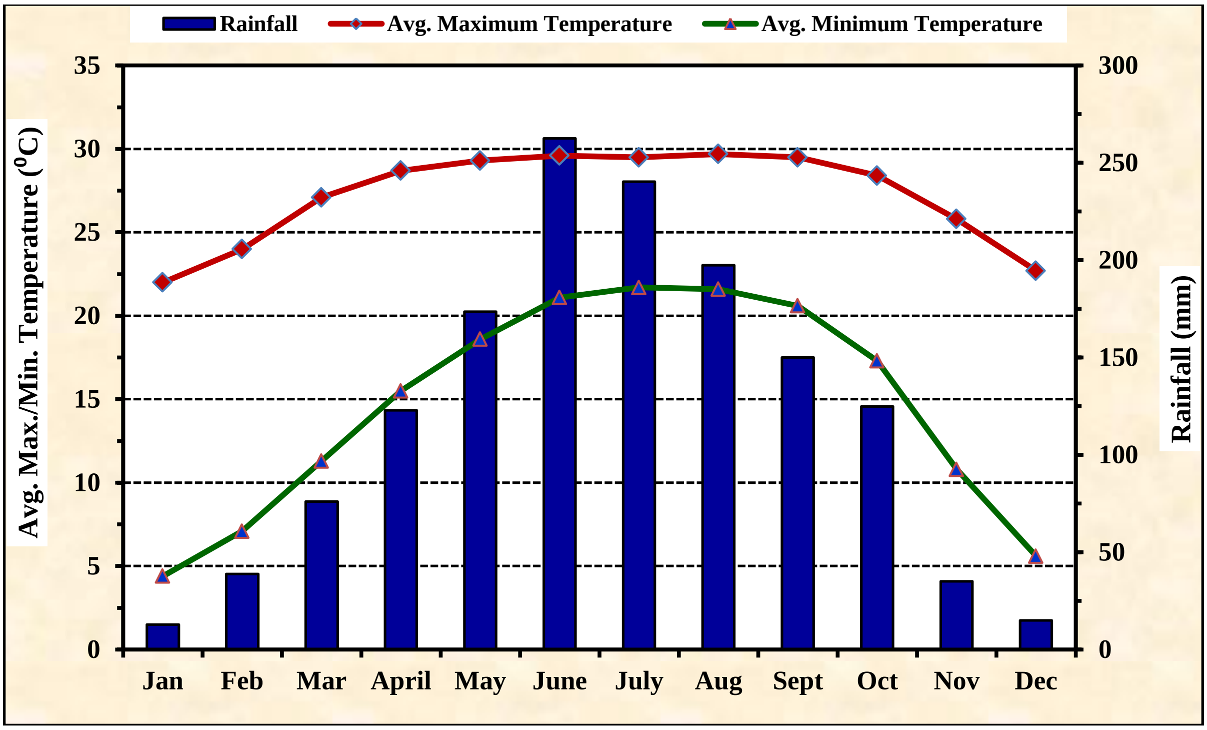


Figure 1. The monthly average maximum, minimum temperature and rainfall (1954-2018).

2.4. Identification of 'Normal', 'Dry' and 'Wet' Years

The 'Normal', 'Dry' and 'Wet' Years were identified using rainfall characterization based on the criteria of IMD (2002), the meteorological drought was described on rainfall departure from its long-term average, and meteorological drought can be declared on weekly, monthly or yearly basis. According to the IMD (2002), the rainfall ≥ +20% of average annual rainfall is considered as excess rainfall; the rainfall between +20% to –20% of average annual rainfall is considered as 'Normal' rainfall; the rainfall between –20% to –60% of average annual rainfall is considered as deficient rainfall, and rainfall≤ –60% of average annual rainfall is considered as scanty rainfall. In this study, the year 2011 was considered as 'Normal' Year and year 2014 and 2017 were considered as 'Dry' and 'Wet' Years, respectively.

2.5. Crop Evapotranspiration

The crop evapotranspiration (ET_c) was evaluated using the reference evapotranspiration (ET_o), which included a wide range of meteorological conditions and the crop coefficient (K_c) at different stages of crop growth. The crop evapotranspiration (ET_c) was estimated as:

$$ET_c = K_c \times ET_o \qquad (1)$$

2.6. Reference Crop Evapotranspiration (ET_o)Using the FAO-56Method

The evapotranspiration rate from a reference crop surface, without any moisture stress, can be considered as the reference crop evapotranspiration and is represented by ET_o. The evaluation of reference evapotranspiration using the FAO-56 method is suggested as the standard method (Vu et al., 2005;Suleiman and Hoogenboom, 2007; Yin et al., 2008; Ralloa et al., 2017). The equation of reference evapotranspiration (ET_o) for the FAO-56 method (Allen et al., 1998) was calculated as:

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

where, ET_o= 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 = mean daily temperature at 2 m height in ºC, 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/ ºC), γ = psychrometric constant (kPa/ ºC), and u_2= wind speed at 2 m height in m/s.

2.7. Crop Coefficients

The FAO-56Table 12 (Allen et al., 1998) includes the representative values for crop coefficients (K_c) of various crops for initial, mid-season and late-season of crop growth stages. The tabulated values of FAO-56 crop coefficients were adjusted for local weather conditions using local meteorological data using the standard equation as specified below:

$$K_{cmid} = K_{cmid(tab)} + [0.04(u_2 - 2) - 0.004(RH_{min} - 45)](\frac{h}{3})^{0.3} \quad (3)$$

$$K_{cend} = K_{cend(tab)} + [0.04(u_2 - 2) - 0.004(RH_{min} - 45)](\frac{h}{3})^{0.3} \quad (4)$$

where, $K_{c\ ini}$= K_c value for the initial stage of the crop, $K_{c\ mid\ (tab)}$= tabulated value of $K_{c\ mid}$ in Table 12 of FAO-56, u_2= average daily wind speed at 2 m height during mid-crop growth stage over grass in m/s, RH_{min}=mean value for daily minimum relative humidity during the late-season stage [%],for 20% ≤RH_{min}≤ 80%, h = mean plant height during the late-season stage [m], for 0.1 m ≤ h ≤ 10 m, and K_{c-end} (tab) = value for K_{c-end} in Table 12 of FAO-56.

2.8. Effective Rainfall

To measure crop water requirements, it is important to determine the amount of water in the soil that would be received from the rainfall in the root zone of the crop. Thus, the rainfall must be measured and the effective rainfall can be determined from the measured rainfall. Effective precipitation is the portion of total precipitation that potentially reduces the net amount of irrigation water needed by plants. Effective rainfall was computed according to the method developed by the USDA Soil Conservation Service (Dastane, 1974). The equations used are given below.

$$P_{eff} = P(125 - 0.2P)/125 \text{ for } P \leq 250 \text{ mm}$$

$$P_{eff} = 125 + 0.1P \text{ for } P > 250 \text{ mm} \quad (3)$$

Where, P_{eff}= effective rainfall (mm/month); P= total precipitation (mm/month).This technique is extensively used for evaluating effective rainfall (e.g., Tsanis and Naoum, 2003; Loukas et al.,2007;Mahmoud and Gan, 2019, Singh et al., 2020).

2.9. Crop Irrigation Requirement (CIR)

The Crop Irrigation Requirement (CIR) for each crop was computed bysubtracting the effective rainfall from the crop water demand (Smith, 1992). TheCIR for non-paddy crops was computed as follows:

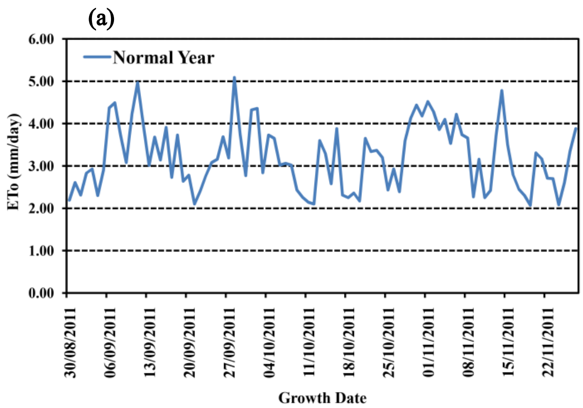
$$CIR = A \times \sum_{i=1}^{n} (ET_{ci} - P_{ei}) \quad (3.18)$$

where, CIR = crop irrigation requirement (m^3 $season^{-1}$), A = crop cover area (m^2), ET_{ci}= crop evapotranspiration on the i^{th} day of a season (m day^{-1}), P_{ei}= effective rainfall on the i^{th} day of a season (m day^{-1}), ET_o= reference evapotranspiration (m day^{-1}), K_c= crop coefficient, and n = number of days in a season.

3. Results and Discussion

3.1 Reference Evapotranspiration (ET_o)

The total reference evapotranspiration (ET_o) during 'Normal', 'Dry' and 'Wet' Years are calculated at 289 mm, 300 mm and 285 mm , respectively. During 'Normal' Year, reference evapotranspiration (ET_o) varies from 2.19 to 4.97 mm/day in initial stage with standard deviation (SD) of 0.80 mm/day, while in development stage ET_o varies from 2.10 to 5.09 mm/day and standard deviation 0.75; whereas in mid-season stage ET_o varies from 2.17 to 4.78 mm/day and standard deviation 0.78; and in late-stage, ET_o varies from 2.07 to 3.88 mm/day with standard deviation (SD) of 0.60 mm/day. On the other hand during 'Dry' Year, reference evapotranspiration (ET_o) varies from 2.33 to 5.13 mm/day in the initial stage with standard deviation (SD) of 0.82 mm/day, whereas in development stage ET_o varies from 2.29 to 4.96 mm/day and standard deviation 0.65; whereas in mid-season stage ET_o varies from 2.29 to 4.30 mm/day and standard deviation 0.62; and in late-stage, ET_o varies from 1.97 to 3.69 mm/day along with standard deviation (SD) of 0.53 mm/day. Likewise in 'Wet' Year, reference evapotranspiration (ET_o) varies from 2.20 to 4.57 mm/day in initial stage having SD of 0.72 mm/day, although in development stage ET_o varies from 2.20 to 4.64 mm/day and standard deviation 0.78; while in mid-season stage ET_o varies from 1.79 to 4.33 mm/day and standard deviation 0.75; and wherein late-stage ET_o varies from 1.96 to 4.04 mm/day through standard deviation (SD) of 0.82 mm/day. The variation of reference evapotranspiration (ET_o) during 'Normal', 'Dry' and 'Wet' Years is given in Fig. 2(a-c).



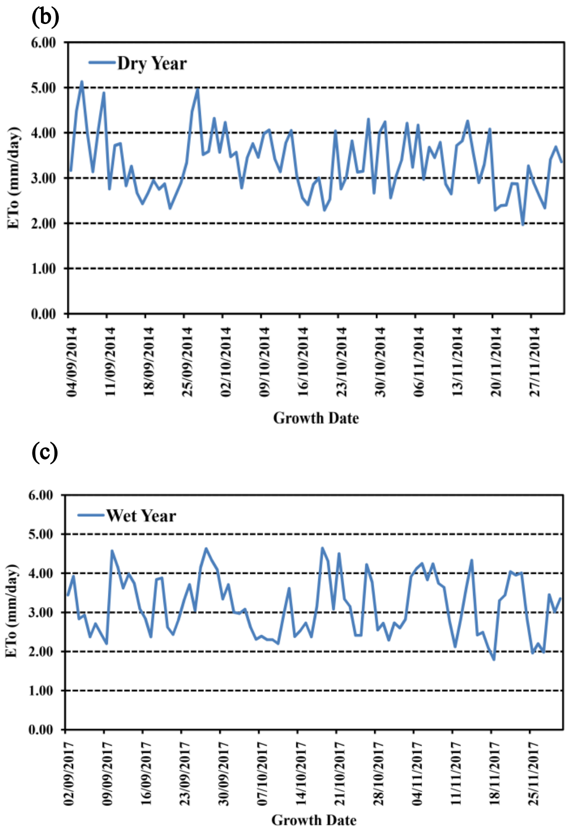


Figure 2(a-c). The variation of reference evapotranspiration (ET_o)during ‘Normal’, ‘Dry’ and ‘Wet’ Years

3.2.Variation of Crop Coefficient (K_c)

The minimum, maximum and standard deviation of crop coefficients during the development stage of French bean is estimated at 0.52, 1.05 and 0.16, respectively in 'Normal' Year. 'During the mid-season stage of French bean, minimum K_c is obtained at 0.89 in 'Dry' Year and followed by 0.91 and 0.93, respectively, during 'Wet' and 'Normal' Years. On the other hand, during the mid-season stage of French bean, maximum K_c is estimated at 1.09 in ‘Normal’ Year, followed by 1.08 and 1.02 during ‘Wet’ and ‘Dry’, respectively. Similarly, during the late-season stage of French bean minimum, K_c is 0.92 in ‘Normal’ Year and followed by 0.85 in ‘Dry’ Year and 0.80 in ‘Wet’ Year. In contrast, during the late-season stage of French bean, maximum K_c is calculated at 1.04 in ‘Wet’ Year, followed by 1.03 in ‘Normal’ Year and 1.00 in ‘Dry’ Year, respectively. The standard deviation (SD) during the mid-season stage of French bean varies from 0.03 to 0.05, whereas SD during the late-season stage of French bean varies from 0.04 to 0.06. The variation of crop coefficient (K_c) of French bean for crop growth during ‘Normal’, ‘Dry’ and ‘Wet’ Years is given in Fig. 3(a-c).

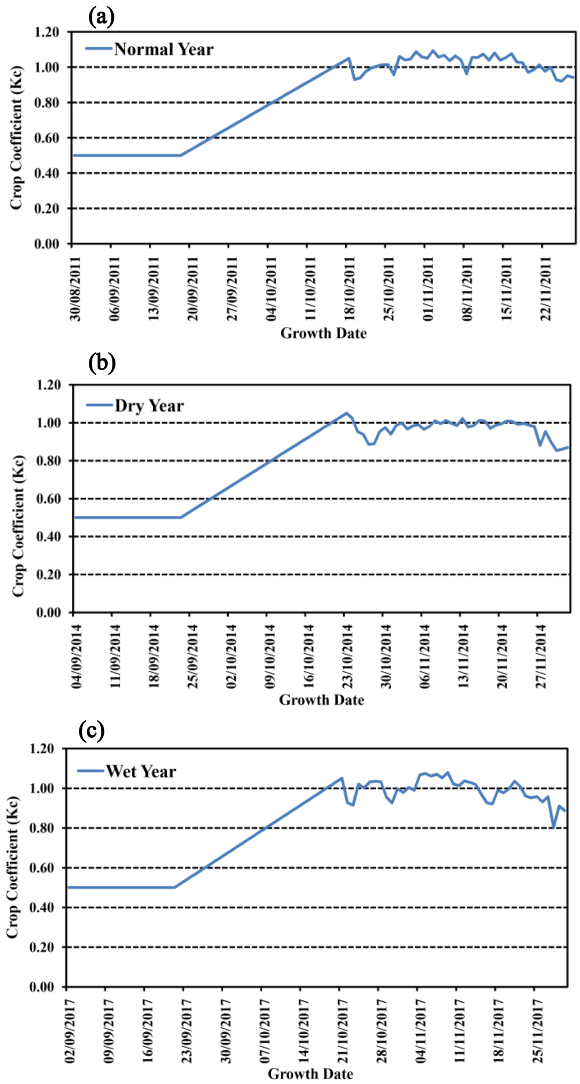
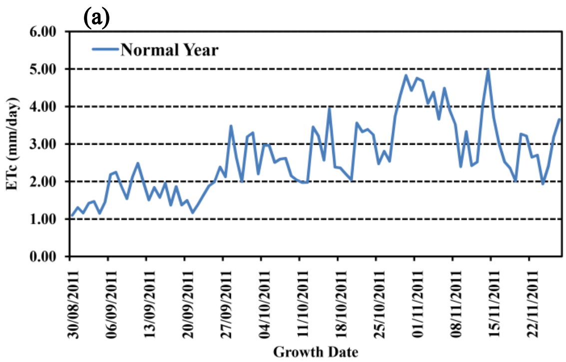


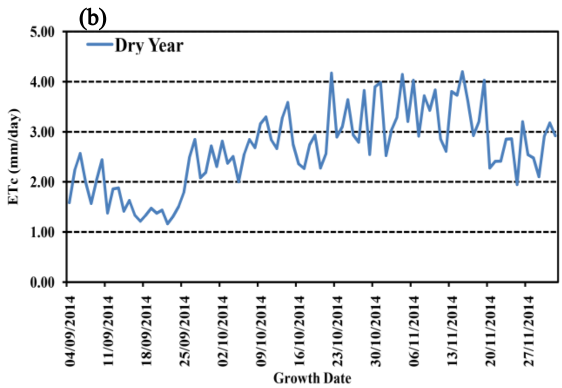
Figure 3(a-c). The variation of crop coefficient (K_c) of French bean for crop growth during ‘Normal’, ‘Dry’ and ‘Wet’ Years

3.3.Crop Evapotranspiration (ET_o)

The total crop evapotranspiration (ET_c) during the growth period of French bean is estimated at 238, 239 and 231 mm during ‘Normal’, ‘Dry’ and ‘Wet’ Years, respectively. For the duration of ‘Normal’ Year, crop evapotranspiration (ET_c) varies from 1.10 to 2.49 mm/day in the initial stage with standard deviation (SD) of 0.40 mm/day, although in the development stage ET_cvaries from 1.17 to 3.93 mm/day and standard deviation 0.69; while in mid-season stage ET_c varies from 2.04 to 4.97 mm/day and standard deviation 0.87; and in late-stage, ET_c varies from 1.93 to 3.65 mm/day with standard deviation (SD) of 0.58 mm/day. Moreover, during ‘Dry’ Year, crop evapotranspiration (ET_c) varies from 1.17 to 2.57 mm/day in the initial stage with standard deviation (SD) of 0.41 mm/day, whereas in the development stage ET_c varies from 1.50 to 4.17 mm/day and standard deviation 0.53; whereas in mid-season stage ET_c varies from 2.28 to 4.20

mm/day and standard deviation 0.59, and in late-stage ET_c varies from 1.95 to 3.20 mm/day along with standard deviation (SD) of 0.42 mm/day. Further during ‘Wet’ Year, crop evapotranspiration (ET_c) varies from 1.10 to 2.29 mm/day in initial stage having SD of 0.36 mm/day, although in the development stage ET_c varies from 1.46 to 4.73 mm/day and standard deviation 0.82; at the same time as in mid-season stage ET_c varies from 1.77 to 4.56 mm/day and standard deviation 0.86 mm/day, and on the contrary in late-stage ET_c varies from 1.88 to 4.18 mm/day through standard deviation (SD) of 0.86 mm/day. The variation of crop evapotranspiration (ET_c) during ‘Normal’, ‘Dry’ and ‘Wet’ Years is given in Fig. 4(a-c).





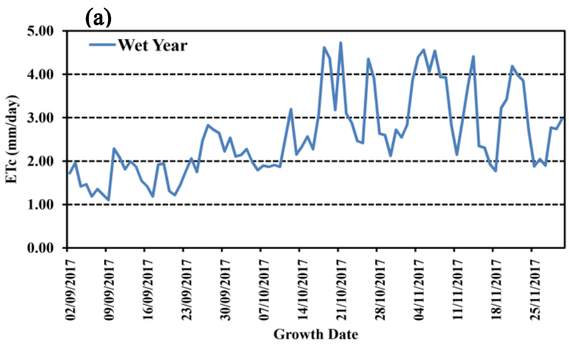


Figure 4 (a-c). The variation of crop evapotranspiration (ET_o) during ‘Normal’, ‘Dry’ and ‘Wet’ Years.

3.4. Effective Rainfall

The effective rainfall is estimated at 164.3, 106.2 and 311.4 mm during ‘Normal’, ‘Dry’ and ‘Wet’ Years, respectively. During the initial stage, effective rainfall varies 74.6 mm in ‘Normal’ Year, 58.0 mm in ‘Dry’ Year and 108.0 mm in ‘Wet’ Year, respectively. Similarly, during the crop development stage, effective rainfall obtained 70.2 mm in ‘Normal’ Year, 41.0 mm in ‘Dry’ Year and 149.4 mm in ‘Wet’ Year, respectively. In the same way, during the mid-season stage, effective rainfall obtained 19.5 mm in 'Normal' Year, 7.2 mm in 'Dry' Year and 52.0 mm in 'Wet' Year, respectively. In the case of the late-season stage, effective rainfall is only obtained in ‘Wet’ Year. The variation of effective rainfall during ‘Normal’, ‘Dry’ and ‘Wet’ Years is given in Table 1.

Table 1. The variation of effective rainfall during ‘Normal’, ‘Dry’ and ‘Wet’ Years.

Growth Stage	Growth Duration (Days)	Effective Rainfall (mm)		
		‘Normal’ Year	‘Dry’ Year	‘Wet’ Year
Initial stage	20	74.6	58.0	108.0
Crop development stage	30	70.2	41.0	149.4
Mid-season stage	30	19.5	7.2	52.0
Late season stage	10	0.0	0.0	2.0
Total	**90**	**164.3**	**106.2**	**311.4**

3.5 Crop Irrigation Requirement (CIR)

The crop irrigation requirement is estimated at 134.4, 161.8 and 88.7 mm during 'Normal', 'Dry' and 'Wet' Years, respectively. The comparison between crop evapotranspiration (ET_c), effective rainfall and crop irrigation requirement during 'Normal', 'Dry' and 'Wet' Years is given Fig. 5. During 'Normal' Year, the crop irrigation requirement (CIR) varies for different stages with no CIR in the initial stage, 21.4 mm of CIR in the crop development stage, 85.7 mm in mid-season stage, and 27.4 mm CIR in late season stage. Similarly, in 'Dry' Year, CIR varies for different stages with no CIR in the initial stage, 43.1 mm of CIR in the crop development stage, 91.7 mm in mid-season stage, and 27.0 mm CIR in late season stage. In the case of 'Wet' Year, in both initial and crop development stages, there is no CIR, while mid-season and late-season stages have CIR 61.7 and 27.0 mm, respectively. There is no CIR in some stages during crop growth due to the effective rainfall and where there is less effective rainfall correspondingly increase in CIR in all the stages. The variation of crop irrigation requirement during 'Normal', 'Dry' and 'Wet' Years is given in Table 2.

Table 2. The variation of crop irrigation requirement during 'Normal', 'Dry' and 'Wet' Years

Growth Stage	Growth Duration (Days)	Crop Irrigation Requirement (mm)		
		'Normal' Year	'Dry' Year	'Wet' Year
Initial stage	20	0.0	0.0	0.0
Crop development stage	30	21.4	43.1	0.0
Mid-season stage	30	85.7	91.7	61.7
Late season stage	10	27.4	27.0	27.0
Total	**90**	**134.4**	**161.8**	**88.7**

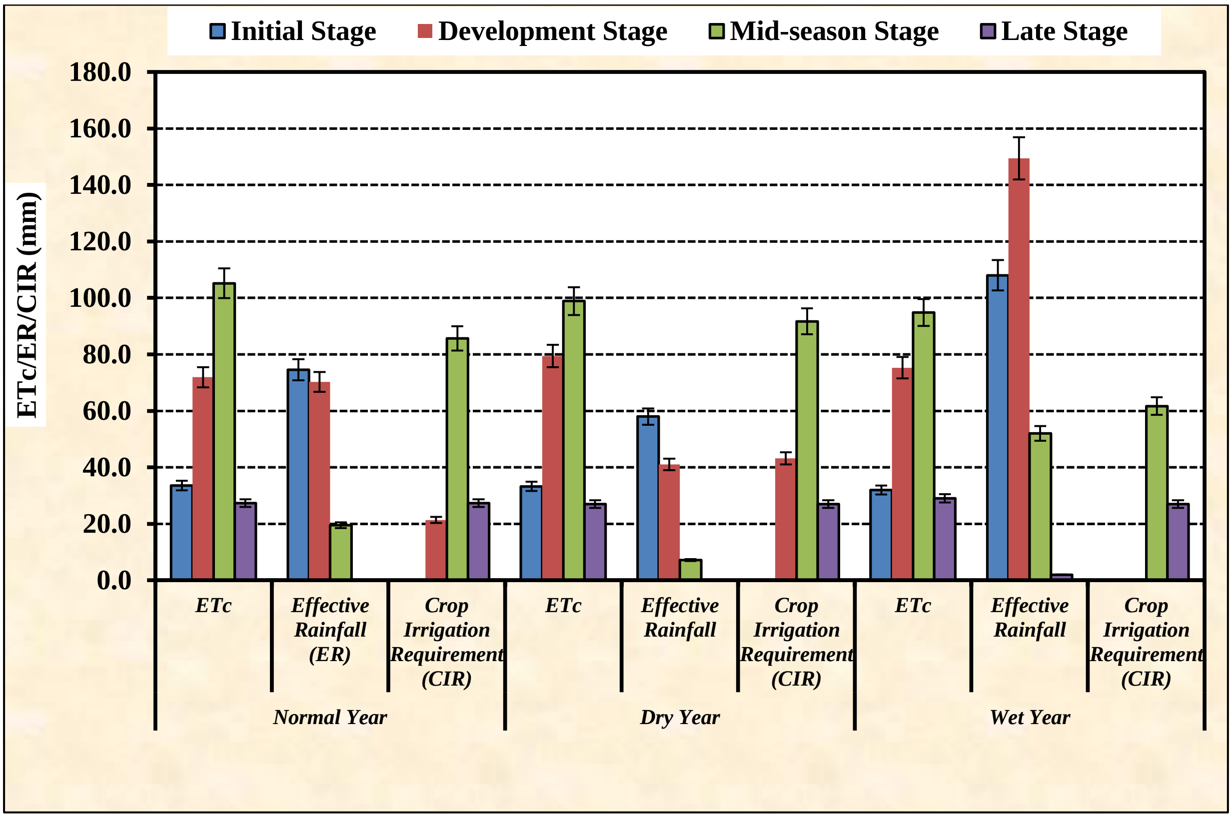


Figure 5. The comparison between crop evapotranspiration (ET_c), effective rainfall and crop irrigation requirement during 'Normal', 'Dry' and 'Wet' Years.

4. Conclusions

In conclusion, this study was to analyzed the reference evapotranspiration (ET_o) calculated by FAO-56 Penman–Monteith method, crop coefficient and effective rainfall using 'Normal', 'Dry' and 'Wet' Years data to identify crop irrigation requirement under varying meteorological conditions in Imphal West district of Manipur, northeast India. The crop irrigation requirement predicted using crop evapotranspiration (ET_c) and effective rainfall will serve as predicting the water management of French bean for sustainable production. The information of effective rainfall and $ET_c$of curve will persist to provide as an instructive tool to educate managers, farmers and learners about the certainties, tendency, performances and constrictions of water consumption.

5. Conflict of Interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

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