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Calculation of Rice Water Requirement for An Giang Province Under the Impacts of Climate Variability

Truong An Dang and Van Hao Lam
University of Science VNU-HCM, 227 Nguyen Van Cu Str., 5 District,
Ho Chi Minh City, Vietnam

Abstract: The study area is one of the important agricultural areas in the Mekong Delta of Vietnam. It has an important contribution in term of food security and economic development in Vietnam. In recent years, this area has seriously impacted by salinization, drought due to the impact of climate change leading to the irrigation water scarce for agricultural production. Therefore, the accurate estimation of irrigation water requirements is very necessary and especially in the context of the climate variability. The aim of this study was to define irrigation water requirement, net irrigation requirements and to conduct efficient irrigation schedule for improved irrigation practices order to provide information necessary in taking decisions on irrigation management under the impacts of climate change. This study is conducted applying the CORPWAT crop model based on meteorological factors recorded from 2004-2015. The simulated results showed that the crop water demand of the Winter-Spring, Summer-Autumn and crop water demand cropsvarying from 0.0-176.8 mm/dec. The high crop water demand was recorded in the Winter-Spring, Summer-Autumn crops (from 593.4-827.8 mm) and lower was observed in the Autumn-Winter crop (236.3 mm). The highest Crop Water Demand (CWD) values of Winter-Spring, Summer-Autumn crop was occurred from the mid-second decade to the end of the third decade and the lowest CWD value was close to zero on the four decades to the mid-sixth decade of the Autumn-Winter crop.The simulation results showed that CORPWAT crop model can be successfully applied to define reference Evapotranspiration (ET_0), actual Evapotranspiration (ET_C), Effective Rainfall (ER), CWD and irrigation conditions with reasonable accuracy.

Key words: Irrigation water, Crop Model, effective rainfall, water scarce, climate change, food security

INTRODUCTION

The rainfall is one of the major factors which impacts on crop production, especially agricultural production (Shah *et al*., 2015; Feng *et al*., 2007). In recent years, under the impact of climate change, the distribution of rainfall at the regions of the world is changing (APN., 2010; MNRE., 2016). While rainfall plays a very important role and is considered as the main factor for irrigation activities which significant influence on farmer's production. In the study area, crops irrigation water is based on local rainfall and fresh water which come from the upper Mekong River (MNRE., 2016). In the dry season, water level at almost irrigation channels is low reduced and it is created favorable conditions for salt water from the sea to pervade deep into the irrigation channels which hinders irrigation for planting crop. Therefore, the increases of irrigation water by rainfall during dry seasonal period is considered essential for agricultural production activities in the context of water scarcity due to drought and salinization, they are threatening for the agricultural activities (MNRE., 2016; Wani *et al*., 2017). Croitoru *et al*. considered rainfall as one of two important factors which can directly be reflected by climate change. Feddema and Freire (2001) concluded that global warming will affect water sources and agricultural production activities. Their results showed that water lost to runoff may increase deficits during rainy seasons, thus, causing crops to suffer higher water stress during the dry season. Adeniran *et al*. (2010) reported that the growth and development stages of crops depend on rainfall factor. They showed that too little/much rainfall will affect the agricultural activities and crop yields. In the agricultural sector, irrigation water is considered as the key factor, therefore, rainfall is considered as an important source to supply soil moisture. Each planting crop has different irrigation water requirement and it is varied according to the time, season. The rate of water uptake required to the plant growth processes in the stages of planting development depends on irrigation water, soil properties, cultivars and meteorological factors (Smith, 1992; Feng *et al*., 2007).

Corresponding Author: Truong An Dang, University of Science VNU-HCM, 227 Nguyen Van Cu Str., 5 District, Ho Chi Minh City, Vietnam

In this study, the CORPWAT crop model is selected to simulate the rice water requirement for three plating crops including Winter-Spring, Summer-Autumn and Autumn-Winter based on the meteorological factors namely sunshine, temperature, humidity, rainfall.

MATERIALS AND METHODS

Study area: The study area is located in the lower Mekong Delta of Vietnam with a total area 3536 km^2 and it has the Eastern border with Dong Thap Province, the North and Northwest borders the provinces of Kandal and Takeo of Cambodia with a border of nearly 104 km, the Southwest of Kien Giang Province and the South border with Can Tho City. It lies from 10°12-10°57'N Latitudes and 104°46-105°35'E Longitudes (Fig. 1). It has a complex terrain with elevations ranging from 0.5-2.5 m above mean sea level (Vu *et al*., 2008; Danh and Khai, 2014). In the study area, agricultural is considered the main sector with two or three rice planting crops per year based on fresh water come from the Mekong River and local rainfall (Vu *et al*., 2008; Danh and Khai, 2014). It has the lowest annual average rainfall in the region with values approximately 1353-1516 mm (Fig. 2). According to Adeniran *et al*. (2010), the critical phases of plant development in the tropical area mainly depend on rainfall factor. Their results also showed that crop water demand depends on not only soil type, growing seasons, the plant varieties but also climatic conditions.

Model description: CORPWAT crop model is conducted to simulate crop water requirement, to design irrigation schedules and management of irrigation schedules by the land and water development division of food and agriculture organization. In addition, this model also allows the conduction of recommendations for improved irrigation practices, planning of irrigation schedules under varying irrigation water conditions and different weather conditions (Smith, 1992). The Penman-Monteith method is used in the CORPWAT Model to define potential Evaporation (ET_o) while actual Evaporation (ET_C) is defined based on ET_o and K_C the crop coefficient (Adeniran *et al*., 2010; Saravanan and Saravanan, 2014). First, the CORPWAT Model define ET_o on a 10-days basis as:

$$ET_O = \frac{0.408\Delta\left(R_n - G\right) + \gamma\frac{900}{T+273}u_2\left(e_s - e_a\right)}{\Delta + \gamma\left(1 + 0.34u_2\right)} \quad (1)$$

Where:

- ET_o = Reference evaporation (mm/day^{-1})
- R_n = The net radiation at the crop surface (Mjdaym^{-2})
- G = Soil heat flux density (Mjdaym^{-2})
- T = Mean daily air temperature at 2.0 m height (°C)
- u_2 = Wind speed at 2.0 m height (m/sec^{-1})
- e_s = The saturation vapor pressure (kPa)
- e_a = Actual vapor pressure (kPa)
- Δ = The slope of the vapor pressure curve (kPa°C^{-1})
- c = Psychrometric constant (kPa°C^{-1})

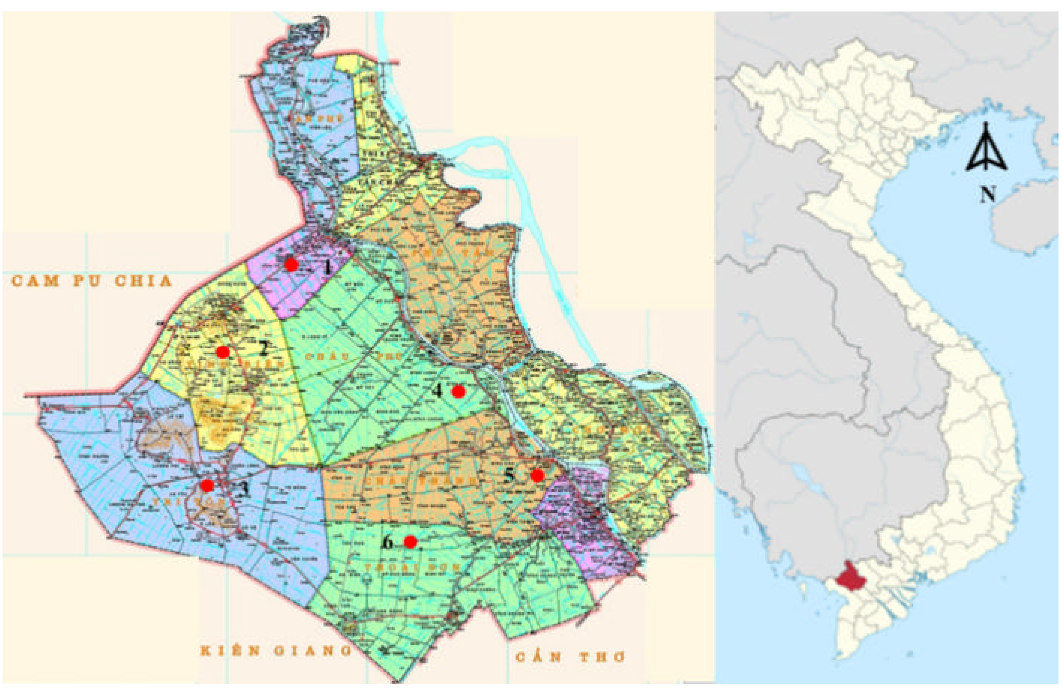

Fig. 1: Illustration of weather stations in the study area

Table 1: Monthly values of climatic parameters for the study area

	Temperature (°C)						
Months	Min	Max	Humidity (%) ($MJ/m^2/day$)	Wind (ms^{-1})	Sun shines (h)	Net radiation	Rainfall (mm)
Jan	16.9	34.8	78	2.5	6.8	17.4	5.30
Feb	19.5	36.6	77	3.3	7.2	19.2	1.24
Mar	17.4	37.5	76	3.2	6.9	19.8	19.70
Apr	22.8	38.4	78	3.1	7.1	20.5	75.80
May	23.1	38.7	80	3.0	6.4	19.0	184.30
Jun	22.7	39.6	84	4.7	6.1	18.2	104.90
Jul	22.5	35.3	84	4.3	5.2	17.0	175.40
Aug	21.4	35.5	84	4.7	5.2	17.3	209.70
Sep	22.8	34.9	84	4.2	5.4	17.5	258.90
Oct	21.9	33.7	83	2.7	5.8	17.3	228.40
Nov	20.6	33.9	80	2.4	6.8	17.6	144.50
Dec	17.5	33.8	79	2.5	6.4	16.4	29.80

Table 2: Crop calendar for rice crops planted in the study area

Crop/Seasons	Crop length (day)	Sowing date	Harvesting date
Winter-Spring	115	15-Dec	29-Mar
Summer-Autumn	115	15-Apr	28-Jul
Autumn-Winter	115	15-Aug	27-Nov

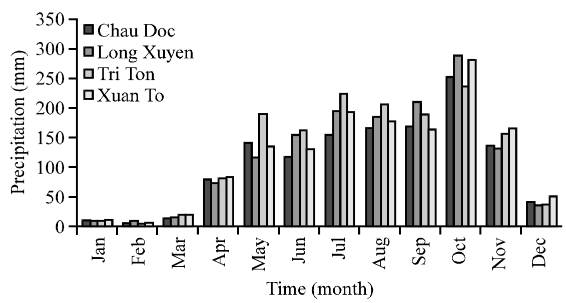

Fig. 2: Annual mean rainfall in the study area in the period 2004-2015

Then, actual evapotranspiration is defined by Eq. 2:

$$ET_C = ET_O * K_C \quad (2)$$

Where:

ET_C = The actual evapotranspiration by the crop (mm/day^{-1})

K_C = The crop coefficient at a specific growth stage and it depends on the type of planting crop and change in the the development stage of a crop

To define irrigation water demand for each plating crop it is first essential to define the Effective Rainfall (ER) over the cultivated area (Arku *et al*., 2012; Bhat *et al*., 2012). The ER can be defined by Eq. 3 (Table 1-4):

$$ER = P_{month} \frac{125\text{-}0,2 * P_{month}}{125} \quad (3)$$

where, ER and P_{month} are effective rainfall (mm) and is the total rainfall (mm); finally, crop water demand for each crop can be calculated Eq. 4:

Table 3: Planting and harvesting dates, growing and crop growth stage coefficient (K_C)

	Crop coefficient (K_C)				Growth stages (days)			
Crop/Season	LP	I	D	L	LP	I	D	L
Winter-Spring	0.30	0.50	1.05	0.70	10	10	65	30
Summer-Autumn	1.05	1.20	1.73	1.15	10	10	65	30
Autumn- Winter	1.05	1.15	1.69	1.10	10	10	65	30

LP = Land Preparation stage; I = Initial stage; D = Development stage; M = Mid-season stage;, L = Late season stage and K_C = crop coefficient

Table 4: Relevant soil characteristics

Soil descriptions	Values
Maximum rain infiltration rate	105 (mm/day)
Plowing depth	20 (cm)
Maximum water depth	70 (cm)
Water availability at planting	5 (mm)
Maximum rooting depth	90 (cm)
Maximum percolation rate after puddling	407 (mm/day)
Critical depletion for puddle cracking	104
Drainable porosity	13 (%)
Initial soil moisture depletion	0
Initial available soil moisture	140 (mm/m)
Total available soil moisture	140 (mm/m)

$$Q = \sum_{i=0}^{n} A_i \left(ET_c\text{-}ER\right) * 10 \quad (4)$$

Where:

Q = Crop water requirement (m^3day^{-1})

I = Crop index

A_i = The crop planted area (ha)

ET_C = Crop evapotranspiration (mm/day^{-1})

Input data: To calculate crop water demand, climate data and cropping patterns were required. Where input data for simulating ET_0 including temperature (maximum, minimum), relative humidity, wind speed, solar radiation, sunshine duration, rainfall. The meteorological data was collected from the Southern Regional Hydro-Meteorological Center of the Vietnam during for a period of 12 years (2004-2015).

In addition, detail crop calendar for rice crops planted in the study area is also shown in Table 2. Three main growing seasons in the year including Winter-Spring, Summer-Autumn and Autumn-Winter with crop coefficient (K_c), growth stages, crop length, sowing and harvesting date for various crops is shown in Table 3.

In this study, the soil characteristics are predominantly silly-clay mix clay (Table 4). The soil pH about 4.0 showing the soil is mostly acidic which means that the soils available have high potentials for retaining plant nutrients.

RESULTS AND DISCUSSION

Reference and actual evapotranspiration: The calculation results of the ET_0 of three rice crops showed that the ET_0 varies in the range of 3.7-5.0 mm/day. The ET_0 increases gradually approximately from 3.99 mm/day in January to the peak value of 5.16 mm/day in April. Then it decreases gradually 3.73 mm/day in December. The high ET_0 occurred in May to July as saw in Fig. 3 and it can be explained by the change in air temperature because of the high air temperature and low rainfall in this period.

The monthly variation of ET_0 indicates that sowing time can affect significantly CWD for a particular type of crop. The Et_0 values varied greatly through three crops and the Et_0 value was recorded, approximately 124.9 mm/month in the Autumn-Winter crop. While, the highest ET_0 values was recorded 155.07 mm/month in the April of the Summer-Autumn crop and the lowest Et_0 values were recorded 115.67 mm/month in the January of the Winter-Spring crop (Fig. 3). The reduction of the ET_0 values in the Winter-Spring crop because of the lower air temperature and increase rainfall in this period. The results obtained from the 15-year climatic data were used in the CORPWAT 8.0 to determine the ET_0 for the study area. The results show that ET_0 was lowest during the rainy season to highest during the Summer season. The calculated values of Et_0 at the peak is 6.08 mm/day at the beginning stage, slightly reduced at growing stage 5.20 mm/day, at mid-stage reaches 3.58 mm/day and at the last stage reaches 1.36 mm/day. The main cause of this decrease is due to an increase of rainfall.

Figure 4 shows that the average ET_C of Winter-Spring, Summer-Autumn and Autumn-Winter crops were approximately 5.29, 5.91 and 5.06 mm/day, respectively. Total of the field ET_C of Winter-Spring, Summer-Autumn and Autumn-Winter crops was calculated 634.9, 717.4 and 615.3 mm/crop, respectively.

Effective Rainfall (ER): The simulated results of the ER are shown in Fig. 5. Results showed that the ER in the study area varied from 0.0-184 mm/month. The maximum ER was recorded 184 mm/month in October. This can be explained by low air temperature and the rainy season in this period. Whereas the ER values were close to zero from January-April. Its decline reduction maybe explained by the high air temperature and low rainfall during the Winter-Spring crop.

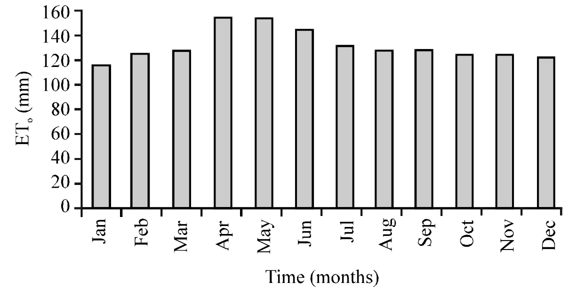

Fig. 3: Simulation results of ET_O with time

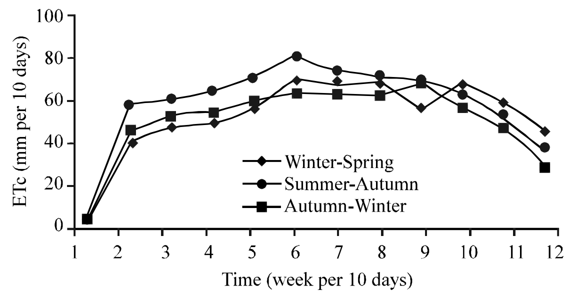

Fig. 4: Calculation results of ET_C from three rice crops

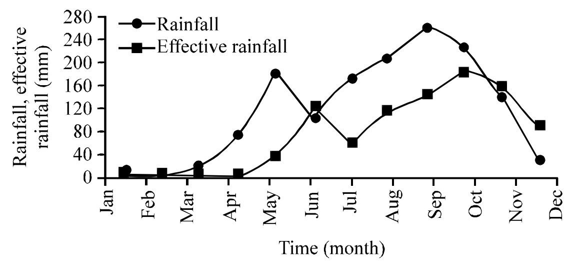

Fig. 5: Simulation results of ER and rainfall with time

Standardized Precipitation Index (SPI): According to McKee *et al.* (1993), the SPI used as the classification system to define drought intensities. Figure 6 showed the drought intensities in the study area for the period 1984-2015. The analyzed results of the SPI showed that the drought occurred in the study area from 2012-2015. The SPI is continuously negative and reaches an intensity from -0.47 to -0.73 in the year 2012, 2013, respectively and conditions further deteriorated in the year 2014, 2015 when SPI reaches from -1.15 to -1.67 corresponding to the rainfall deficit reached 28.9 and 38.7% (Fig. 6), respectively (moderate and severe drought conditions) (FAO., 2016; Lee and Dang, 2018).

Table 5: Evapotranspiration and irrigation requirement for three crops

		ET_C (mm)			ER (mm)			CWD (mm)		
Day	Stage	WS	SA	AW	WS	SA	AW	WS	SA	AW
5	LP	4.0	5.3	4.3	0.8	0.7	4.5	80.0	81.3	80.3
10	I	40.3	58.2	45.9	0	9.6	47.5	153.9	174.1	62.3
30	D	154.2	196.7	168.5	0.2	105	175.5	154.1	91.7	1.7
35	M	206	226.1	188.9	0	76.6	172.3	206	149.4	16.6
30	L	230.5	223.5	200.4	1.5	126.8	130.3	228.6	90.5	63.5
Total		634.9	717.4	615.3	2.57	318.4	531.9	827.8	593.4	236.3

LP = Land Preparation stage; I = Initial stage; D = Development stage; M = Mid-season stage; L = Late season stage; K_C = crop coefficient; ET_C = crop Evapotranspiration; IR = Irrigation Requirement; WS = Winter-Spring; SA = Summer-Autumn and AW = Autumn-Winter

Table 6: Simulation of Winter-Spring crop under irrigated condition

Date	Days	Stage	Rain (mm)	Percol (mm)	Depl. SM (mm)	Net Gift (mm)	Loss (mm)	Depl. SAT (mm)
10-Dec	-4	LP	0	0	1	76.0	0	26.0
11-Dec	-3	LP	0	56.5	2	61.6	0	11.6
13-Dec	-1	LP	2.8	6.3	2	51.9	0	1.9
18-Dec	4	I	0	4.7	0	95.0	20	-5.0
27-Dec	13	D	2.2	4.7	0	96.5	20	-3.5
05-Jan	22	D	0	4.7	0	102.8	20	2.8
13-Jan	30	D	0.5	4.7	0	97.2	20	-2.8
21-Jan	38	D	0	4.7	0	103.2	20	3.2
28-Jan	45	M	0	4.7	0	96.8	20	-3.2
04-Feb	52	M	0	4.7	0	98.7	20	-1.3
11-Feb	59	L	0	4.7	0	99.9	20	-0.1
18-Feb	66	L	0	4.7	0	101.7	20	1.7
25-Feb	73	L	0	4.7	0	102.4	20	2.4
04-Mar	80	L	0	4.7	0	99.7	20	-0.3
11-Mar	87	L	0	4.7	0	98.0	20	-2.0
19-Mar	95	L	0	4.7	0	100.9	20	0.9
28-Mar	104	L	0	4.7	0	97.5	20	-2.5
29-Mar	End	L	0	4.7	0	-	-	-

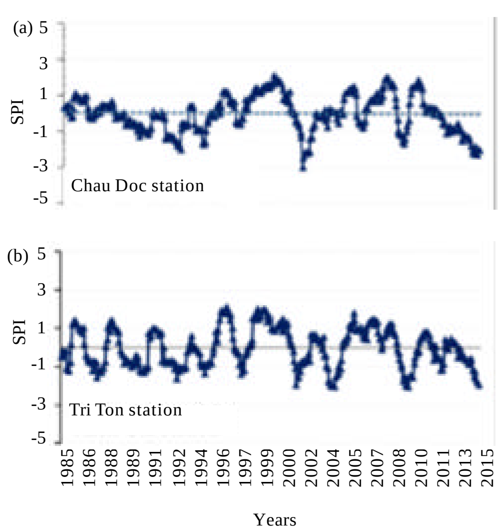

Fig. 6: a,b) Illustration of SPI at some stations in the study area (Lee and Dang, 2018)

Crop Water Demand (CWD): The analyzed results showed that the CWD in the An Giang Province varying from 0 .0-176.8 mm/dec. The results showed that the CWD for the Winter-Spring, Summer-Autumn crops (approximately from 593.4-827.8 mm/crop) were higher the Autumn-Winter crop (236.3 mm/crop)

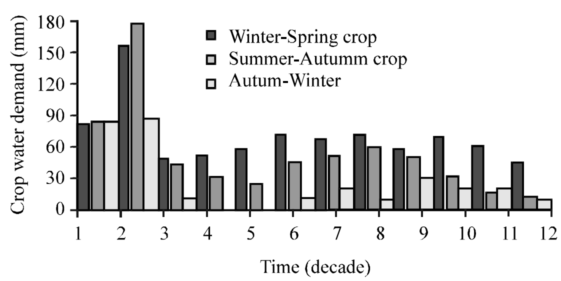

Fig. 7: Illustration of crop water demand for Winter-Spring, Summer-Autumn and Autumn-Winter in the study area

(Table 5). The average CWD values of Winter-Spring, Summer-Autumn and Autumn-Winter crops were varying from 18.88 mm/dec from 69.77 mm/dec. The highest CWD values of Winter-Spring, Summer-Autumn crop was recorded from the mid-second decade to the end of the third decade and the lowest CWD value was close to zero (from the four decades to the mid-sixth decade) of the Autumn-Winter crop (Fig. 7) (Table 6).

Irrigation conditions: Irrigation is very required when rainfall is not sufficient to compensate for the water lost by evapotranspiration and percolation. The calculation results of irrigated conditions, depletion of saturation for

Table 7: Simulation of Summer-Autumn crop under irrigated condition

Date	Days	Stage	Rain (mm)	Percol (mm)	Depl. SM (mm)	Net gift (mm)	Loss (mm)	Depl. SAT (mm)
10-Apr	-4	LP	0	0	2	76.0	0	26.0
11-Apr	-3	LP	0	56.5	0	63.8	0	13.8
14-Apr	0	LP	0	8.8	0	61.7	0	11.7
20-Apr	6	I	0	4.7	0	102.0	30	2.0
30-Apr	16	D	0	4.7	0	102.5	30	2.5
11-May	27	D	0	4.7	0	104.2	30	4.2
21-May	37	D	0	4.7	0	100.7	30	0.7
30-May	46	M	0	4.7	0	97.7	30	-2.3
08-Jun	55	M	0	4.7	0	99.1	30	-0.9
15-Jun	62	M	0	4.7	0	99.4	30	-0.6
22-Jun	69	L	0	4.7	0	100.9	30	0.9
30-Jun	77	L	0	4.7	0	104.7	30	4.7
11-Jul	88	L	0	4.7	0	102.4	30	2.2
22-Jul	99	L	0	4.7	0	99.4	30	-0.6
28-Jul	End	L	0	0	0	-	-	-

Table 8: Simulation of Autumn-Winter crop under irrigated condition

Date	Days	Stage	Rain (mm)	Percol (mm)	Depl. SM (mm)	Net gift (mm)	Loss (mm)	Depl. SAT (mm)
10-Aug	-4	LP	0	0	1	76.0	0	26.0
11-Aug	-3	LP	0	56.5	0	62.3	0	12.3
16-Aug	2	I	0	4.7	0	103.2	40	3.2
22-Aug	8	I	0	4.7	0	96.4	40	-3.6
01-Sep	18	D	0	4.7	0	99.1	40	-0.9
12-Sep	29	D	0	4.7	0	102.2	40	2.2
22-Sep	39	D	0	4.7	0	105.1	40	5.1
01-Oct	48	M	0	4.7	0	96.8	40	-3.2
11-Oct	58	M	0	4.7	0	98.5	40	-1.5
21-Oct	68	M	0	4.7	0	99.3	40	-0.7
31-Oct	78	L	0	4.7	0	104.3	40	4.3
11-Nov	89	L	0	4.7	0	103.0	40	3.0
21-Nov	99	L	0	4.7	0	100.4	40	0.4
27-Nov	End	L	0	0	0	-	-	-

each stage is carried out for various crops. The primary objective of irrigation scheduling calculation is to apply water at the right period and in the enough amount. In other words it applied at fixed interval per stage. The irrigation requirement and conditions calculated over a specific period as shown in Table 6-8.

CONCLUSION

The development stage and mid-season of three rice crops indicating that ET_C is higher than ET_o and leading to an increased crop water demand in the development and mid-season stages. The simulation results analysis showed that in both conditions rainfed and irrigated, the largest yield reduction occurred in stage three developmental stages. The results obtained from the study can be used as a guide to farmers whom can apply the amount and frequency of irrigation water for the crops. The results will enhance understanding of crop water demand which will consequently help improve the productivity. The much longed for the attainment of stability in food security, reduction in poverty.

The model CORPWAT can appropriately predict ET_o, effective rainfall, crop water demand and irrigation conditions caused by crop water deficit which makes this model as a good tool for irrigation planning, irrigation management and sowing calendar.

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