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Irrigation Scheduling of Rice (*Oryza sativa* L.) Using CROPWAT Model in the Western Region of Bangladesh

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Abstract

Understanding of crop water requirement is essential for irrigation scheduling and selection of cropping pattern in any particular area. A study was conducted to estimate irrigation requirement and made irrigation scheduling of *T. Aman* (wet season) and *Boro* (dry season irrigated) rice in the western region of Bangladesh using CROPWAT model. Historical climate data from three weather stations in the region along with soil and crop data were used as input to FAO Penman-Monteith method to estimate reference evapotranspiration (ET_o). Effective rainfall was calculated using USDA soil conservation method. The model estimated1408 mm annual ET_o in the study area, of which the highest amounts of 175 mm was in April and the lowest (70 mm) in December. The average annual rainfall was 1592 mm of which 986 mm was effective for plant growth and development. The model estimated ET_c of BRRI dhan49, which was 473 to 458 mm, depending on its transplanting dates from 15 July to 15 August. Rice transplanted on 15 July required no irrigation, whereas three supplemental irrigations amounting 279 mm were required for transplanting on 15 August. The CROPWAT model estimated seasonal irrigation water requirement of 1212 mm (12 spilt applications) for BRRIdhan28 transplanted on 15 January. This model has also a potentiality to make irrigation scheduling of other crops.

Keywords: Water requirement, *T. Aman* and *Boro* rice, evapotranspiration, irrigation scheduling.

1. Introduction

The global population has been projected to be 9.1 billion in 2050 that is 34% higher than current population. Thus, demand for annual cereal food will increase from 2.1 billion to about 3 billion tons (FAO, 2009). Additional food and fiber production and sustaining the production at that level without compromising environmental integrity are the major challenges. At present, increasing population in the world is creating additional claim on water resources. According to FAO (2014), nearly 40 percent of the world's food is produced from irrigated agriculture. Moreover, competition for fresh water in other sectors is increasing worldwide (IWMI, 2010). That is why improved planning and management are necessary for proper use and distribution of water among different sectors. Intensification of agriculture through the use of high yielding varieties, fertilization, irrigation and crop protection measures remain the most likely options to combat the challenge of increased food production. Fortunately, there are opportunities to conserve and significantly improve effective use of water by agriculture sector (Aghdasi, 2010).With the introduction of several system-research tools relating to information technology likes geographic information system (GIS), global positioning system (GPS), remote sensing (RS), modeling etc., farmers can now refine site specific nutrient recommendations and water management. Proper plan for the application of desired amount of water at the right time can conserve water resources. Among other options, CROPWAT (Smith, 1991) aided irrigation scheduling that can serve the purpose.

CROPWAT is a FAO recommended model for irrigation management designed by Smith (1991) that integrates climate, crop and soil to assess reference evapotranspiration (ET_o), crop evapotranspiration (ET_c) and irrigation water requirements and more specifically the design and management of irrigation schemes (Saravanan and Saravanan, 2014).

Over 90 percent of the world's rice (*Oryza sativa* L.) is produced and consumed in Asia (IRRI, 2012). Although fresh water availability for agriculture is declining in many Asian countries (Postal, 1997), its demand for rice is increasing (Pingali *et al.*, 1997). Approximately 50 percent of the fresh water is used for rice production in Asia (Guerra *et al.*, 1998). About 75 percent of the global demand of rice is fulfilled from irrigated rice culture in lowland (Maclean *et al.*, 2002). However, decreasing water availability for agriculture threatens productivity of the irrigated rice ecosystem (Guerra *et al.,* 1998). Many scientists are skeptical about the role of genetic engineering and biotechnology in improving water use efficiency (Boutraa, 2010), since manipulation of genes might not significantly improve such complex trait. So, means and ways must be devised to save water and increase water use efficiency for irrigated rice culture (Guerra *et al.*, 1998).

In Bangladesh, water demand for house-hold, agriculture and industry is increasing very fast (Bindraban, 2001). As a result, regulation on water allocation is one of the critical issues for the policy makers. Since good quality irrigation water is gradually becoming scarce, it should be used judiciously. One of the major approaches could be application of right amount of water to the crops at the right time. With this view, study was undertaken to estimate the irrigation requirement and time of irrigation of *T. Aman* and *Boro* rice in the western region of Bangladesh.

2. Materials and Methods

2.1 Site selection

The study area was in the western region of Bangladesh (24.1-23.2 °N and 89.1-89.2 °E, altitude 7 to 14 m above mean sea level).The site includes Pabna, Kushtia, Chuadanga, Jessore, Jhenaidah and Meherpur districts, which belong to the agro-ecological zone (AEZ)-11 (High Ganges river floodplain) and AEZ-12 (Low Ganges river floodplain) (FAO, 1988). AEZ-11 covers 43% silt loam, 32% loamy and 12% clayey soil and it has an area of 1321062 ha. AEZ-12 has 797139 ha with 31% clayey soil, 29% silty clay and 13% silt loam (FAO, 1988). Silt loam soil was considered in this study since it covers the maximum area in Bangladesh.

2.2 Calculation of reference Evapotranspiration (ET$_o$)

ET_o was calculated according to Penman-Monteith method using CROPWAT 8.0 model. The Penman–Monteith equation (FAO, 1998) integrated in the CROPWAT program is expressed by equation (1) as follows;

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

where, ET_o is reference crop evapotranspiration (mm d^{-1}); R_n is net radiation at the crop surface(MJ $m^{-2}d^{-1}$);G is soil heat flux (MJ $m^{-2}d^{-1}$); T is average air temperature(°C); U_2 is wind speed measured at 2 m height (m s^{-1}); (e_a–e_d) is vapor pressure deficit (kPa); Δ is slope of the vapor pressure curve (kPa°C^{-1}); γ is psychrometric constant (kPa °C^{-1}) and 900 is a conversion factor.

The FAO -CROPWAT 8.0 model (FAO, 2009) incorporates procedures for estimating ET_o and crop water requirements and allows simulation of crop water use under various climate, crop and soil conditions. Average maximum and minimum temperatures (°C), relative humidity (%), wind speed (m s^{-1}) and sunshine hours (h) were collected from data from Bangladesh Meteorological Department (BMD) from 1970 to 2013 for Ishwardi and Jessore and from1989 to 2013 for Chuadanga. The latitude, longitude and altitude of the stations were also collected. The ET_o was calculated for every 10 days (defined as “decade” by FAO) and then accumulated to monthly data.

2.3 Calculation of effective rainfall

CROPWAT model considers four methods as fixed percentage, FAO/AGLW formula, empirical formula and USDA soil conservation service method to estimate effective rainfall. In this study, the USDA soil conservation service method (Pongpinyopap and Mungcharoen, 2012) was utilized to estimate effective rainfall as;

$$P_{effective} = P_{total}\frac{(125 - 0.2P_{total})}{125} \quad for\ P_{total} < 250\ mm \ldots\ldots\ldots\ldots (2)$$

$$P_{effective} = (125 + 0.1P_{total}) for P_{total} > 250\ mm \ldots\ldots\ldots\ldots (3)$$

Where, $P_{effective}$ = effective monthly rainfall (mm), P_{total}= total monthly rainfall (mm)

2.4 Crop data

Rice was grown in *T. Aman* and *Boro* seasons. Rice growing period was divided as:

(i) nursery/land preparation (seedling stage, 30 days in *T. Aman* and 40 days in *Boro*)
(ii) initial stage (transplanting to seedling establishment, usually 10 days)
(iii) crop development stage (tillering to panicle initiation)
(iv) mid stage (panicle initiation to 100% flowering, 30 days) and
(v) late stage (flowering to maturity, 30 days)

In this study, irrigation scheduling was done for popular *T. Aman* variety, BRRI dhan49 (135 days duration) and *Boro* variety, BRRI dhan28 (140 days duration).Three transplanting dates (15 July, 1and 15 August) were considered for BRRI dhan49 depending on farmer’s choice. In *Boro* season, farmers usually transplant *Boro* varieties from the last week of December to middle of February and grow the crop under fully irrigated condition. For simplification, 15 January was considered as a suitable transplanting date since most of the farmers’ follow this practice in the study region. Maximum rooting depth of rice was considered 40 cm.

2.5 Soil data

Bulk density of soil was1.5 g cm^{-3} with maximum infiltration rate 40 mm day^{-1}. Moisture content at field capacity and wilting point were 26.8% and 12.9%, respectively. Drainable porosity was approximately 18% (BRRI, 2014). Default value of maximum percolation rate in the model was 3.4 mm day^{-1} for silt loam soil.

2.6 Estimation of irrigation water requirement and time of application

Crop irrigation water requirement (CWR) refers to the amount of water that needs to be supplied, while crop evapotranspiration (ET_c) refers to the amount of water that is lost through evapotranspiration (Allen *et al.*, 1998). CWR (mm) was determined according to FAO (2005) as;

$$CWR_i = \sum_{t=0}^{T}(Kc_i.ET_o - P_{eff.}) \ldots\ldots\ldots\ldots (4)$$

Where Kc_i is the crop coefficient of the given crop i during the growth stage t and T is the final growth stage. The crop evapotranspiration $ET_c = K_c \times ET_o$ where K_c is crop coefficient and ET_o = reference crop evapotranspiration (mm day^{-1}).

Default value of K_c for rice by FAO in the model was used in calculation of actual evapotranspiration. Model considered K_c dry value was 0.7, 1.05 and 0.7 in nursery, development and late stage respectively. Where K_c wet value was 1.2, 1.2 and 1.05 for nursery, development and late stage respectively.

Since rice is a water loving crop, suitable time of irrigation was considered when moisture level went down to field capacity. In case of silt loam soil, 18% desaturation indicates the field capacity and it needs 3 days to reach the field capacity from saturation (BRRI, 2015). So, three days after disappearing of standing water was considered as suitable time of irrigation. Irrigation efficiency was assumed 70%. Irrigation was not applied in the last 10 days of its growing period because water in this stage would delay ripening of crop.

3. Results and Discussion

3.1 Reference evapotranspiration

The model estimated mean annual reference evapotranspiration of rice crop, which was 1408 mm for western part of Bangladesh. The observed ET_o values were higher (more than average) during March to August and lower during September to February (Table 1).The highest monthly ET_o (175 mm) was found in April and the lowest (70 mm) in December. In March to May, low relative humidity and high temperatures resulted in increased evapotranspiration. On the other hand, high humidity along with low temperature and sunshine hours reduced evapotranspiration in the rainy season. Lower ET_o value in winter (November to February) was the result from the lower values of temperature, sunshine hours and wind speed.

Table 1. Average climatic data (Ishurdi, Chuadanga and Jessore stations) and reference crop evapotranspiration (ET_O) for western region of Bangladesh

Month	Min temp (°C)	Max temp (°C)	Humidity (%)	Wind speed (m s^{-1})	Sunshine (h)	Solar radiation (MJ $m^{-2}day^{-1}$)	ET_o (mm $month^{-1}$)
January	9.3	26.1	76.0	0.9	6.4	13.7	70.9
February	12.3	29.8	70.0	1.1	7.7	17.2	89.0
March	16.9	34.7	65.0	1.7	7.8	19.5	143.6
April	21.6	37.1	69.0	2.6	8.0	21.4	175.1
May	23.3	36.7	75.0	2.6	7.4	21.1	173.8
June	25.0	35.1	83.0	2.4	4.9	17.4	133.1
July	25.5	33.4	87.0	2.2	4.2	16.2	120.3
August	25.5	33.5	86.0	2.0	4.8	16.7	122.6
September	24.9	33.6	86.0	1.6	5.0	15.9	112.0
October	21.8	33.0	83.0	0.9	6.6	16.3	109.8
November	16.3	30.7	78.0	0.7	7.4	15.3	88.2
December	11.2	27.1	78.0	0.7	6.4	13.1	70.1
Average	19.5	32.6	78.0	1.6	6.4	17.0	117.3
Total							1408

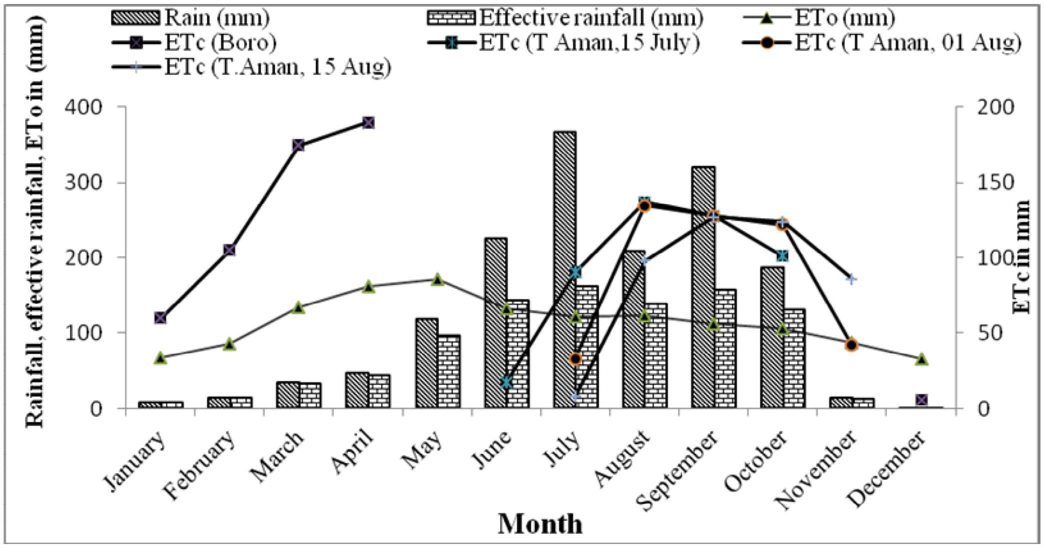

Figure 1. Distribution of average rainfall, effective rainfall, reference evapotranspiration over the months and rice crop evapotranspiration in western part (Pabna, Kushtia, Meherpur, Chuadanga and Jessore) of Bangladesh.

3.2 Rainfall vs. reference crop evapotranspiration

Figure 1 illustrates average monthly total rainfall, effective rainfall and ET_o for the study area. Average annual rainfall in the region was 1592 mm of which 986 mm was effective for plant growth and development. The highest rainfall (340 mm) was in July followed by September (285 mm). About 72 percent of total rainfall occurred during June to September. The effective rainfall was only 159 mm in July and 154 mm in September (Figure 1). Generally, rainfall during June to October is sufficient to meet evapotranspiration requirement of rice crop. For other seven months of the year, ET_o exceeds effective rainfall in which irrigation is indispensable for growing crop without yield reduction. Although abundant rainfall occur in wet period, its uneven distribution often delays transplanting and causes terminal drought in the study region (BRRI, 2015).

3.3 Rice evapotranspiration and irrigation requirement

Rice evapotranspiration and irrigation requirement at different growth stages are provided in Table 2. *T. Aman* rice, transplanted on 15 July, had no demand for irrigation because of adequate rainfall. About 645 mm effective rainfall was enough to meet 473 mm ET_c. But, 1 August transplanting required 40 mm irrigation in late stage of the crop. Similarly, 15 August transplanting needed 10 mm irrigation in mid stage and 73 mm irrigation in late stage. If a medium duration rice variety is transplanted on 1 August, ET_c would be 459 mm with an effective rainfall of 582 mm. However, if such type of variety is transplanted on 15 August, ET_c would be 443 mm having 511 mm effective rainfall. *Boro* rice is cultivated in dry period of the year when rainfall is not sufficient (Figure 1) to meet ET_c demand and thus depends on irrigation. A medium duration rice variety (140 days), transplanted on 15 January, accounted for 575 mm irrigation water including land preparation during its growing period. Estimated ET_c was 505 mm with 110 mm effective rainfall (Table 2). Dry season rice had higher ET_c than wet season rice that is an agreement with FAO (2009) and Bouraima *et al.* (2015). This was because of some climatic factors such as more rainy days and less sunshine hours in the wet season and longer growing season and high evaporation in dry season.

Table 2. Crop evapotranspiration and irrigation requirement at different growth stages of rice in western region (Pabna, Kushtia, Meherpur, Chuadanga and Jessore) of Bangladesh

Transplanting date	Stage	Duration	Kc	∑Etc	Eff. rain. (mm)	IR (mm)
15 July	Seedling/land prep	0-30	1.2	29.4	135.9	0
	Initial	31-40	1.09	42.3	67.7	0
	Development	41-75	1.12±0.02	154	172.8	0
	Mid	76-105	1.14	133.63	168.42	0
	Late	106-135	1.08±0.06	113.27	100.4	0
	Total	135		472.6	645.22	0
1 August	Seedling/land prep	0-30	1.2	32.7	153.4	0
	Initial	31-40	1.1	43.2	50.5	0
	Development	41-75	1.13±0.02	156.25	178	0
	Mid	76-105	1.15	124.75	137.4	0
	Late	106-135	1.08±0.006	101.9	62.3	39.6
	Total	135		458.8	581.6	39.6
15 August	Seedling/land prep	0-30	1.2	15.9	129.8	
	Initial	31-40	1.1	43	49.2	
	Development	41-75	1.13±0.02	158.2	188.33	
	Mid	76-105	1.15	126.15	116.51	9.64
	Late	106-135	1.09±0.06	99.39	26.26	73.13
	Total	135		442.64	510.1	82.77
15 January	Seedling/land prep	0-40	1.2	25.4	9.4	195.9
	Initial	41-50	1.09	26.0	2.8	23.2
	Development	51-80	1.16±0.06	102.8	17	85.8
	Mid	81-110	1.22	158.1	30.5	127.6
	Late	110-140	1.15±0.07	192.2	50.1	142.1
	Total	140		505	110	575

3.4 Irrigation scheduling of T. Aman and Boro rice

Rice transplanted on 15 July required no supplemental irrigation since rainfall was adequate to meet the demand of crop. About 94 mm gross irrigation at 81 days after transplanting needed to apply for 1 August transplanting (Table 3). Delay transplanting on 15 August required one irrigation at reproductive and two irrigations at ripening phase, amounting 279 mm water (Table 3). If sufficient rainfall would not occur during land preparation, supplemental irrigation would have to apply. It is revealed that no supplemental irrigation is required in *T. Aman* rice cultivation when it is transplanted before 31 July in the study region.

Since *Boro* rice was cultivated under irrigated condition, CROPWAT model estimated 849 mm net irrigation and 1212 mm gross irrigation water requirement (with 70% field efficiency) for successful production. Total numbers of split irrigation applications were 12 including puddling and soaking (Table 3). The higher irrigation requirements during drier months of a season are explained by the severe drought condition and low relative humidity due to lack of rain and high temperatures, which led to increase evapotranspiration. Zhong *et al.* (2014) also observed that when the hottest period with the highest temperature prevailed, high evaporation occurred with rapid decrease in soil moisture implying the highest agricultural water requirement.

Table 3. Irrigation scheduling for *T. Aman* and *Boro* rice cultivation for Western (Pabna, Kushtia, Meherpur, Chuadanga and Jessore) Bangladesh

Date of irrigation	Days to irrigate	Stage	Net irrigation (mm)	Gross irrigation (mm)
15 July transplanting (*T. Aman*)				
no irrigation required				
1 August transplanting (*T. Aman*)				
20-Oct	81	End	65.8	94
15 August transplanting (*T. Aman*)				
20-Oct	67	Mid	66.5	95
4-Nov	82	End	65	93
15-Nov	93	End	63.5	91
Total	03		194	279
15 January transplanting (*Boro*)				
10-Jan	-4	Pre-puddling	72.9	104.1
12-Jan	-2	Puddling	109.8	156.9
21-Jan	7	Initial	65.1	93.0
2-Feb	19	Development	67.5	96.4
12-Feb	29	Development	63.7	91.0
22-Feb	39	Development	68.6	98.0
4-Mar	49	Mid	69.8	99.7
12-Mar	57	Mid	63.3	90.4
20-Mar	65	Mid	65.9	94.1
29-Mar	74	End	68.7	98.1
6-Apr	82	End	66.9	95.6
14-Apr	90	End	66.3	94.7
Total	12		849	1212

Field irrigation efficiency = 70%

4. Conclusions

The estimated mean annual reference crop evapotranspiration was 1408 mm in the study area. Rainfall during June to October was sufficient to meet evapotranspiration demand of crop. Delayed transplanting of *T. Aman* rice experienced terminal drought and needed supplemental irrigation. Transplanting of T. aman rice (BRRI dhan49) on 15 August required 279 mm gross irrigation water, which needed to be applied in three splits. However, about 1212 mm irrigation water (in 12 spilts) was estimated by CROPWAT model for cultivation of Boro rice (BRRI dhan28) if the crop is transplanted on 15 January. Although irrigation requirement varies depending on soil and weather conditions, CROPWAT model can be used for justification of water use in planning irrigation projects.

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