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Determination of Evapotranspiration and Supplemental Irrigation for Aman Rice Cultivation in Dinajpur

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Abstract In this study, attempt was taken to analyze the evapotranspiration and rainfall for beneficial planning of aman rice cultivation in of Dinajpur district of Bangladesh. Two popular Aman rice varieties i.e., BR11, and BR22 were selected because of their popularity in this area. Daily Climatic data like rainfall, daily maximum and minimum temperature, maximum and minimum relative humidity, wind speed and sunshine hour for a period of 20 years (1991–2010) were collected from the Bangladesh Meteorological Department, Dhaka, Bangladesh. By using FAO Penman-Monteith method, reference crop evapotranspiration (ET_o) was determined. Actual evapotranspiration (ET_c) of these varieties was find out multiplying ET_o by crop co-efficient (K_c). Weibull's method was used for Probability analysis and 75% probability level for expected rainfall and evapotranspiration was estimated for BR11 and BR22 varieties for 20 years. Difference in K_c implies the differences in ET_c for total growing season. Supplemental irrigation was estimated after probability analysis. For BR11 supplemental irrigation were needed in development, mid and late stage but in case of BR22, it was needed for mid and late stage. Aman growing period is most precious rice season in Bangladesh. This study was found beneficial for making water schedule for irrigation and enhances aman rice production in this area. Finally this study was helpful for efficient utilizing, managing and conserving valuable water resource for BR11 and BR22 improving cultivation.

Keywords Crop production, Aman variety, Rainfall, ET_c, Probability, Irrigation

1. Introduction

Climate includes patterns of temperature, precipitation (rain or snow), humidity, wind and seasons Exquisite impacts on hydrological systems, ecosystems, agriculture and other related systems have been expected (Lal et al., 1998; McCarthy et al., 2001). Longer growing seasons and warmer temperatures may bring benefit in cold regions may be the positive aspects including some negative impacts of reduction of water availability, greater water demand and more frequent extreme weather. These impacts may put agriculture in serious risks (Eitzinger and Kubu, 2009). Kosa and Pongput (2007) reported that, as much as 10% change in production will associated with a change in growing season precipitation by one standard deviation (e.g. Millet in South Asia). Irrigation based on groundwater is adopted to cultivate high-yielding rice varieties and Bangladesh is the world's fourth biggest rice producing country (Scott and Sharma, 2009; IRRI, 2010). Climate change in Bangladesh is an extremely crucial issue and according to National Geographic (2002), Bangladesh ranks first as the nation most vulnerable to the impacts of Climate Change in the coming decades. The annual rainfall in Bangladesh ranges from 2300 mm (90.6 in) to 2600 mm (102.44 in) but uneven distribution. Ali et al., (2007) found that, the average annual rainfall in Bangladesh in every year was 2486 mm (97.95 inch) and it was about 66.67% of the total year's rainfall. About 70% to 80% of the total rainfall occurs from month of June to September. Also increased the occurrence of climate-related serious issues like floods, droughts, heat waves and cyclones in future (FAO, 2006; IPCC, 2007; Yu et al., 2010; Ahsan et al., 2011). These changes make a great concern about the drastic consequences on the agricultural crop growth and food security in most of the parts of the world, especially in developing countries (FAO, 2007; IPCC, 2007; WB, 2010; Rouder et al., 2011). Uncertain rainfall pattern creates extreme events such as flood, cyclone, drought resulting adverse effect on human life, animals, eco-system and crop yields especially on rice production (GOB and UNDP, 2009. By 2050, the global water demand of agriculture is estimated to increase by a further 19% due to irrigational needs. Worldwide, agriculture accounts for 70% of all water consumption. The largest sector of Bangladesh's economy is 'Agriculture', which is about 20.29% of the GDP and 47.5% of the labor sector (BBS, 2012). Amount of Total rice production 52,231.00.tons, yield 4.42 tons/hectare, covers 11,820.00 hectare (BBS, 2015). Modern technologies adapt new varieties and irrigation system to

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fulfil the food security. Impact of climate change is now the main concern for scientist to overcome production losses, with the increasing population. Evapotranspiration (ET) refers to water used by a crop for its growth, tissue building, cooling purposes as well as soil evaporation (Alkaisi and Broner, 2005). ET rates depend upon the factors such as temperature, humidity, solar radiation, wind speed and vegetation characteristics that is transpiring, with significant variation of vegetation types (Allen et al., 1998). The reference crop evapotranspiration (ET_c) which is defined in FAO-24 as “the rate of ET from an extensive surface of 8 to 15 cm tall, green grass cover of uniform height, actively growing, completely shading the ground and not short of water.” If the ET demand exceeds the available water to the plant, then transpiration may stop resulting in crop loss. Therefore, the accurate estimation of ET along with proper knowledge of precipitation and other factors, soil moisture storage capacity can provide measurement of water need for a crop. According to Bangladesh Rice Research Institute (BRRI, 1991), Aman is almost a completely rain-fed rice that grows in the months of monsoon, although it requires supplemental irrigation during planting and sometimes, in the flowering stage, depending on the availability of rainfall. For calculating crop-water demand, irrigation scheduling, preparing input data to any hydrological water-balance models, and assessing and planning regional water resources and evaluating data, among various climatic factors, Reference Crop Evapotranspiration, ET_o is an important key. A 1-mm loss of water through ET across 1 ha crop field is equivalent to 10 m^3 (268,000 gallons) of water (Allen et al., 1991). This study is done for identifying the dependable rainfall and water requirement at every stage of aman rice (one varieties) for providing accurate amount of water at every stage in future. When rainfall fails to provide sufficient moisture for normal plant growth, in order to improve and increase yields, supplemental irrigation with little amount of water is applied to plants. This study was carried out to estimate ET_c for two Aman varieties, probability analysis for dependable rainfall and determination of stage wise irrigation for these two Aman rice varieties.

2. Methodology

2.1. Study Area and Crop Data

The study was conducted for Dinajpur district, which was situated in north-west hydrological region. Total area of Dinajpur is 3439.98 sq. km, located between 25010´ and 26004´ north latitudes and in between 88023´ and 89018´ east longitudes. Dinajpur is located in tropical monsoon climate. Rainfall is generally heavy during July and August (BBS, 2009). According to the crop sowing time, 1^{st} and 2^{nd} transplanting time was classified. 1^{st} transplanting time indicates the approximately early sowing time for these two varieties and 2^{nd} transplanting time indicates the possible late sowing time.

Figure 1. Map of Dinajpur District

Table 1. Name of rice varieties, releasing year, time of transplanting and growing period

Season	Variety	Release year	Transplantation time	Height cm	Harvest time	Growing period, day
Aman	BR11	1980	15th June-14th July	115	25th October-29th November	145
	BR22	1988	30th June-8th August	105	30th November-15th December	150

Table 2. Length of different growth stages of BR11 and BR22 rice variety

Variety (Aman)	Transplant time	Length of rice growth stages			
		Initial stage	Development stage	Mid stage	Late stage
BR11	1st transplanting	15th June-24th July	25th July-2nd September	3rd September-7th October	8th October-6th November
	2nd transplanting	25th June-3rd August	4th August-12th September	13th September-17th October	18th October-16th November
BR22	1st transplanting	30th June-8th August	9th August-17th September	18th September-22th October	23th October-26th November
	2nd transplanting	16th July-24th August	25th August-3rd October	4th October-7th November	8th November-12th December

2.2. Data and Methods

Some of the climatic data were found partially missing for the selected study area which collected from Bangladesh Meteorological Department, Dhaka, Bangladesh. Missing data was estimated by following equation (Hydrology, H.M. Raghunath):

$$P_x = \frac{P1 \pm P2 \pm \cdots \ldots \ldots \pm Pn}{n} \quad (1)$$

Where, P_x = data of missing station, P_1, P_2….. P_n = data of index stations and n = numbers of index stations.

There are various types of methods used for calculation of reference crop evapotranspiration (ET_o). The Penman-Monteith method is recommended as the sole standard method of determination of ET_o by FAO (Allen et al., 1998). The classic Penman-Monteith method combines both energy and mass balances to model reference evapotranspiration (ET_o) are given below (FAO, 2006):

$$ETo = \frac{0.408\,(Rn - G) + \gamma \frac{900}{T + 273} u2\,(es - ea)}{\Delta + \gamma\,(1 + 0.34\,u2)} \quad (2)$$

Where, Rn=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;

u2= wind speed at 2 m height, m/sec;

es = saturation vapor pressure, kPa;

ea= actual vapor pressure; kPa;

(es - ea)= saturation vapor pressure deficit, kPa;

Δ = slope of vapor pressure curve, kPa/°C and

γ = psychometric constant, kPa/°C.

Crop coefficient (K_c) is a ratio of actual crop evapotranspiration (ET_c) to the reference crop evapotranspiration (ET_o). The growing period of rice has four distinct growth stages: initial, crop development, mid-season and late season. The length of the initial period is highly dependent on the crop, the crop variety, the planting date and the climate.

Allen et al. (1998), K_c for initial stage was considered as 1.05 for both rice varieties.

K_c of the mid-season stage (1.20) was adjusted by considering minimum relative humidity, wind speed and crop height. The equation for adjustment is (FAO, 2006)

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

Where, K_{cmid} =crop coefficient of mid-season stage; U_2 = mean daily wind speed at 2 m height over grass during the late-season growth stage (m/s); RH_{min} = mean daily minimum relative humidity during the mid-season growth stage (%); and h = the mean plant height during the mid-season stage (m).

The crop coefficient of the development stage of rice was derived by empirical equation considering constant crop coefficient values during the initial and mid-season stages. This empirical equation is given (FAO paper no.56):

$$K_{cdev} = K_{cprev} + [\{i\text{-}Y\ (L_{prev})\}/L_{stage}]*(K_{cnext}\text{-}K_{cprev}) \quad (4)$$

Where, K_{cdev} = crop coefficient of rice at crop development stage; i is the day number within the growing season (l= length of the growing season); L_{stage} =length of the stage under consideration (day); $\sum L_{prev}$ =sum of lengths of all previous stages (day); K_{cnext} = crop coefficient at the beginning of next stage and K_{cprev} = crop coefficient at the end of previous stage;

Irrigation was ceased fifteen days before harvest and during the late season stage (Doorenbos et al., 1979). The equation for adjustment is: (FAO, 2006):

$$K_{cend} = 0.90 + [0.04(u_2\text{-}2) - 0.004(RH_{min}\text{-}45)](h/3)^{0.3} \quad (5)$$

Where, K_{cend} = crop coefficient of late-season stage; RH_{min} = mean daily minimum relative humidity during the mid-season growth stage (%); u_2 = mean daily wind speed at 2 m height over grass during the late-season growth stage (m/s) and h= the mean plant height during the mid-season stage (m).

In the crop coefficient approach, actual crop evapotranspiration (ET_c) is calculated by multiplying ET_o by K_c (FAO, 2006):

$$ET_{crop} = K_c \times ET_o \quad (6)$$

Where, ET_{crop} = actual evapotranspiration (mm/day); K_c = crop coefficient at different growing stages and ET_o = reference crop evapotranspiration at different growing stages of rice (mm/day).

Weibull's ranking method was used for probability analysis of 20 years data (1991-2010). According to this method, yearly rainfall and ET_c data were arranged in descending order. Probability was calculated as follows: (hydrology by H.M. Raghunath)

$$P=\frac{m}{N+1}*100 \quad (7)$$

Where, N= total number of data and m = order or rank of the observation from the highest value.

The probabilities thus found were plotted on log-normal probability paper. Rainfall and ET_c were plotted against the corresponding probability on the log normal probability paper and the probability curves were drawn. The expected rainfall and ET_c at probability level of 75% was estimated for different growth stages of BR11 and BR22 1991 to 2010 (20 years).

Supplemental irrigation (SI) at different growth stages of rice in aman seasons under Dinajpur districts was calculated by:

$$SI=Rainfall–Actual\ evapotranspiration \quad (8)$$

3. Results and Discussions

In table 3, Actual evapotranspiration of BR11 at the 1st transplant time varied from 45 to 83 mm in initial stage, 134 to 180 mm in crop development stage, 120 to 154 mm in mid stage and 36 to 58 mm in late stage. In case of 2^{nd} transplant time it varied from 43 to 73 mm in initial stage, 133 to 178 mm in crop development stage, 116 to 145 mm in mid stage and 33 to 72 mm in late stage.

In table 4, Actual crop evapotranspiration of BR22 at the 1st transplant time varied from 40 to 77mm in initial stage, 127 to 179 mm in crop development stage, 116 to 140 mm in mid stage and 33 to 47 mm in late stage. In case of 2^{nd} transplant time it varied from 41 to 77 mm in initial stage, 126 to 179 mm in crop development stage, 112 to 146 mm in mid stage and 28 to 38 mm in late stage.

For BR11 (mentioned in table 5), supplemental irrigation was needed during the development stage, mid stage and late stage for 1^{st} transplanting time and for 2^{nd} transplanting time, supplemental irrigation needed in mid stage and late stage respectively. Similarly, for BR22 (mentioned in Table 6) supplemental irrigation need was detected as mid stage and late stage for 1^{st} transplanting time) and for 2^{nd} transplanting time. In Figure 2(A) and 2(B), data shown was the dependable rainfall at 75% probability level as compared to ET_c for BR11 and BR22 rice variety.

Table 3. Actual crop evapotranspiration ET_c for BR11

Year	ET_c (mm) at different growth stages of BR11							
	1^{st} transplant				2^{nd} transplant			
	Initial	Crop Development	Mid-Season	Late Season	Initial	Crop Development	Mid-Season	Late Season
1991	66	166	122	58	66	148	133	58
1992	54	165	150	39	64	168	135	44
1993	61	152	136	45	66	146	132	41
1994	45	172	147	45	64	165	145	42
1995	65	161	124	40	66	158	123	38
1996	51	151	144	36	53	164	128	39
1997	60	159	128	45	70	147	132	41
1998	46	134	142	37	53	133	144	33
1999	58	144	128	37	66	137	125	36
2000	70	157	134	45	66	150	139	40
2001	66	170	124	42	62	159	132	44
2002	53	157	154	44	45	173	141	44
2003	72	173	140	38	69	174	123	36
2004	50	175	120	38	72	178	116	43
2005	57	147	141	36	68	136	136	34
2006	68	180	138	45	69	174	138	42
2007	46	144	132	37	43	142	145	40
2008	48	155	142	44	62	150	131	38
2009	83	173	142	43	62	143	138	42
2010	53	163	132	38	65	151	126	72

Table 4. Actual crop evapotranspiration ET_c for BR22

Year	ET_c (mm) at different growth stages of BR22							
	1st transplant				2nd transplant			
	Initial	Crop Development	Mid Season	Late Season	Initial	Crop Development	Mid Season	Late Season
1991	61	144	140	42	70	132	133	37
1992	60	169	134	43	69	152	134	37
1993	40	152	129	40	65	134	130	30
1994	67	166	140	34	61	162	122	37
1995	61	159	118	42	56	139	136	33
1996	56	154	130	47	62	151	128	34
1997	67	139	139	41	57	136	139	32
1998	58	133	132	44	47	142	132	32
1999	75	127	131	39	41	132	122	38
2000	64	147	138	39	58	142	135	30
2001	65	150	134	40	75	136	123	37
2002	61	168	135	46	52	163	146	36
2003	71	168	123	33	65	154	112	32
2004	75	149	116	42	74	126	121	35
2005	69	142	119	41	46	151	118	34
2006	66	179	137	37	77	144	132	28
2007	57	131	134	41	56	130	126	37
2008	70	149	134	37	56	145	125	36
2009	50	147	137	39	50	153	128	29
2010	77	141	126	41	51	41	123	34

Table 5. Supplemental irrigation for BR11 in Dinajpur District (Dependable Rainfall and ET_c at 75% probability level

Stages	1st transplanting time				2nd transplanting time			
	Rainfall (mm)	ET_c (mm)	Supplemental Irrigation (mm)	Remarks	Rainfall (mm)	ET_c (mm)	Supplemental Irrigation (mm)	Remarks
Establishment Stage	94	49	_	No need of irrigation	66	62	_	No need of irrigation
Development stage	120	147	27	Irrigation is needed	160	141	_	No need of irrigation
Mid stage	108	127	19	Irrigation is needed	57	120	63	Irrigation is needed
Late stage	120	37	9	Irrigation is needed	0	39	39	Irrigation is needed

Table 6. Supplemental irrigation for BR22 in Dinajpur District (Rainfall and ET_c at 75% probability level)

Stages	1st transplanting time				2nd transplanting time			
	Rainfall (mm)	ET_c (m)	Supplemental Irrigation (mm)	Remarks	Rainfall (mm)	ET_c (m)	Supplemental Irrigation (mm)	Remarks
Establishment Stage	105	59	_	No need of irrigation	60	51	_	No need of Irrigation
Development stage	140	126	_	No need of irrigation	160	128	_	No need of Irrigation
Mid stage	70	119	49	Irrigation is needed	40	118	78	Irrigation is needed
Late stage	0	38	38	Irrigation is needed	0	33	33	Irrigation is needed

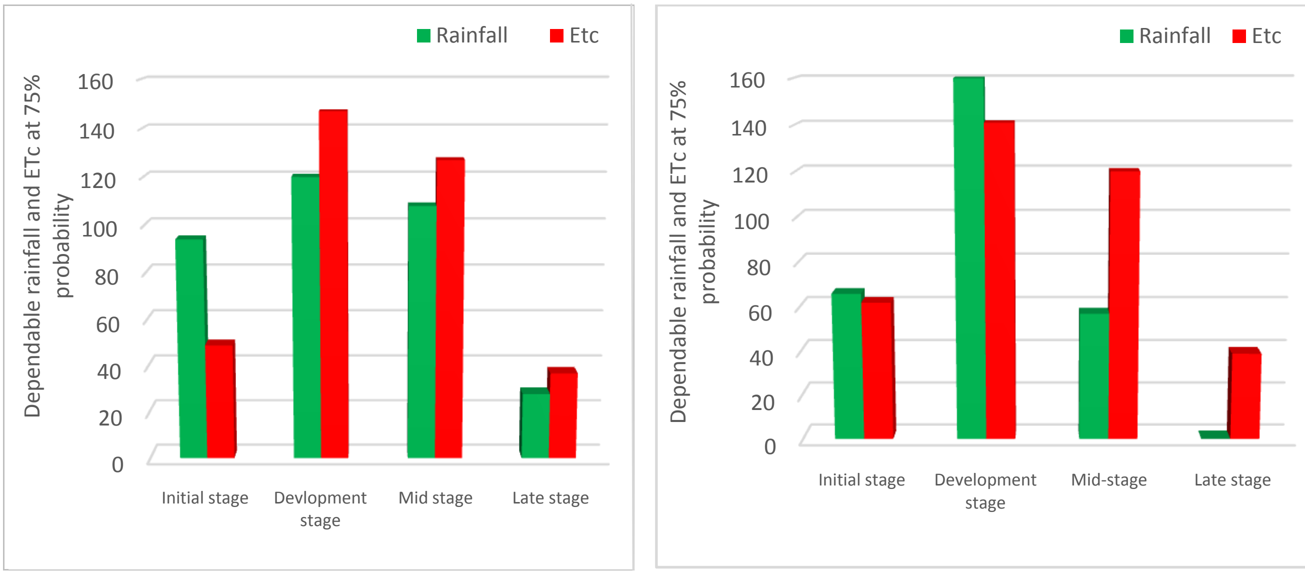

Figure 2(A). Dependable rainfall at 75% probability as compared to ET_c at initial, development, mid and late stages of BR11 for 1st transplanting and 2nd transplanting in Dinajpur

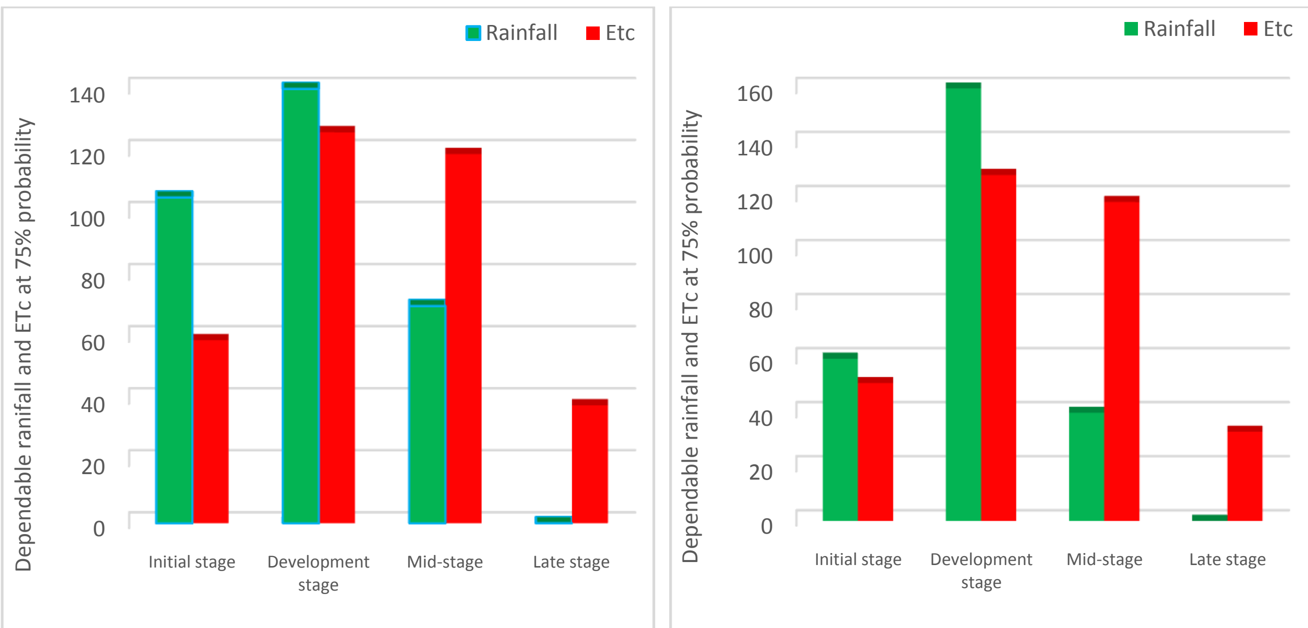

Figure 2(B). Dependable rainfall at 75% probability as compared to ET_c at initial, development, mid and late stages of BR22 for 1st transplanting and 2nd transplanting time in Dinajpur district

4. Conclusions

Major conclusions were drawn on the basis of findings of this study:

i. Adjusted crop coefficients of BR11 and BR22 at different growth stages in different years and sowing times varied due to the changes of relative humidity and wind speed.

ii. Actual crop evapotranspiration of BR11 for 1st transplant time varied from 359 to 441 mm and 363 to 503 mm in Dinajpur districts. For BR22, actual crop evapotranspiration for 1st transplanting varied from 361 to 463 mm and 333 to 393 mm for 2nd transplanting time. Actual crop evapotranspiration varied due to variation of crop coefficient and reference crop evapotranspiration.

iii. For BR11, supplemental irrigation was needed in development, mid and late stage in 1st transplanting, but for 2nd transplanting time, supplemental irrigation was needed in mid and late stages. For BR22, supplemental irrigation was needed mainly in mid and late stages for 1st and 2nd transplanting.

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