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Estimation of supplemental irrigation for *Aman* rice cultivation in Bogra and Dinajpur districts of Bangladesh

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Abstract

A study was carried out to analyze the rainfall and evapotranspiration for successful planning of two aman rice varieties i.e., BRRI dhan33 and BRRI dhan34 in Bogra and Dinajpur districts of Bangladesh. Reference crop evapotranspiration (ET_0) was determined by employing the FAO Penman-Monteith method. By multiplying $ET_0$by crop coefficient (Kc) actual evapotranspiration of the two rice varieties at different growth stages was determined. Probability analysis was done by Weibull's method and the expected rainfall and actual evapotranspiration at 75% probability level were estimated for different growth stages of BRRI dhan33 and BRRI dhan34 for 14 years. The results revealed that the ETc varied over the total growing season. After probability analysis, the supplemental irrigation was calculated for BRRI dhan33 during mid and late stages; but for BRRI dhan34, it was calculated during development, mid and late stages in Bogra and Dinajpur districts. The study was found quite effective to assess the water availability period for aman cultivation and to indicate when supplemental irrigation is necessary. These results may enable to optimize utilization of valuable water resources and will help to create an irrigation schedule for BRRI dhan33 and BRRI dhan34 for their successful cultivation.

Key words: Crop planning, rainfall, ETc, probability, supplemental irrigation

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Introduction

Climate change is an extremely crucial issue in the present world and Bangladesh ranks as the nation most vulnerable to the impacts of climate change. The annual rainfall in the country ranges from 2300 to 2600 mm, but its distribution is uneven. About 70 to 80% of the total rainfall occurs during the months from June to September, leaving the most productive dry season (November to March) with inadequate rainfall for crop growth. It has been predicted that due to climate change, there will be a steady increase in temperature and change in rainfall pattern of Bangladesh (IPCC, 2007). Higher evapotranspiration due to temperature rise will demand higher amount of water for irrigation. At the same time, the higher temperature will change crop physiology and shorten crop growth period, which, in turn, will reduce irrigation days. As climate differs with its regional settings, the rainfall and evapotranspiration rate will also differ for Bangladesh. For the upcoming environmental stresses on water, the evapotranspiration rate is very important to manipulate and compute the water requirement regionally to manage the national water demands effectively. On the other hand, rainfall is the leading climatic event to influence crop production in particular and agriculture in general. Better crop management calls for minimization of the effects of variation of rainfall, especially in rain-fed areas. 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. Peterson *et al.* (1995) analyzed rainfall and evapotranspiration data to determine the rainfall excess and deficit periods in order to aid crop planning and water management practices. Comprehensive information on irrigation requirement and probability of rainfall is required for planning of irrigation strategy and development of appropriate irrigation scheduling for different cropping systems. This study is done for identifying the dependable rainfall and water requirement at every stage of aman rice (two varieties) for providing accurate amount of water at every stage in future. Irrigation has a direct relationship to the crop yield; if irrigation requirement increases, the production cost also increases. By knowing the demand of crop-water requirement statistically, it will be possible to optimize utilization of valuable water resources. Therefore, supplemental irrigation is an effective response to alleviate the adverse impact of soil moisture stress during dry spells on the yield of rain-fed crops. This study may help sustaining agricultural production to contribute in the food security of the country.

Materials and Methods

Data collection: The study was carried out for two districts of Bangladesh, namely, Bogra and Dinajpur to analyze the rainfall and evapotranspiration for planning of irrigation of two aman rice varieties i.e., BRRI dhan33 and BRRI dhan34. Climatic data like daily rainfall, daily maximum and minimum temperature, maximum and minimum relative humidity, wind speed and sunshine hour were collected for a period of 14 years (1997–2010) from the Bangladesh Meteorological Department, Dhaka, Bangladesh. For the two rice varieties, their year of release, growing period, and time of seed sowing, seedling age and growing period of each variety were collected from Bangladesh Rice Research Institute (BRRI, 2006) and a staggered transplanting time was considered.

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

Season	Parameters					
	Variety	**Released year**	**Transplant time**	**Height, cm**	**Harvest time**	**Growing period, day**
Aman	BRRI dhan33	1997	1st July–31st July	100	26th October-26th November	118
	BRRI dhan34	1997	20th July – 25th July	117	2nd December-7th December	135

Missing data interpretation: Some of the rainfall data were found partially missing for the selected study area and these were calculated by simple arithmetic mean method as

$$P_x = \frac{P_1+P_2+\quad+P_n}{n} \quad \ldots\ldots\ldots\ldots\ldots (1)$$

Where P_x is data of missing station; P_1, P_2….. P_n are data of index stations and n is the number of index stations.

Reference crop evapotranspiration: The Penman-Monteith method is recommended as the sole standard method of determination of$ET_0$by FAO (Allen *et al*., 1998).

$$ET_o = \frac{0.408\ (R_n - G) + \gamma \frac{900}{T+273} u_2\ (e_s - e_a)}{+\ \gamma(1 + 0.34u_2)} \text{ ……….. (2)}$$

Where, ET_0 is reference crop evapotranspiration (mm/day), R_n is net radiation at the crop surface (MJ/m^2/day), G is soil heat flux density (MJ/m^2/day), T is air temperature at 2 m height (^oC), u_2 is wind speed at 2 m height (m/s), e_s is saturation vapor pressure (kPa), $e_a$is actual vapor pressure (kPa), (e_s–e_a) is saturation vapor pressure deficit (kPa),   is slope of vapor pressure curve (kPa/^{o}C) and γ is psychometric constant (kPa/^{o}C).

Crop coefficient: Crop coefficient (Kc) is defined as a ratio of actual crop evapotranspiration to the reference crop evapotranspiration. The growing period of rice has four distinct growth stages: initial, crop development, mid-season and late season. The crop coefficient, K_c, of rice was taken as 1.05 for initial stage (FAO, 2006). The equation for determination of crop coefficient at mid stage is:

$$K_{cmid} = 1.20 + [0.04(u_2 \quad 2) \quad 0.004(RH_{min} \quad 45)](\frac{h}{3})^{0.3} \text{ ……… (3)}$$

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

Similarly, for determination of crop coefficient at late stage is:

$$K_{cend} = 0.90 + [0.04(u_2 \quad 2) \quad 0.004(RH_{min} \quad 45)](\frac{h}{3})^{0.3} \text{ …….. (4)}$$

Where, K_{cmid} is crop coefficient for late-season stage,u_2 is mean daily wind speed at 2 m height over grass during the late-season growth stage (m/s), $RH_{min}$is mean daily minimum relative humidity during the late-season growth stage (%), and h is the mean plant height during the late-season stage (m). Finally, the crop coefficient at development stage is:

$$K_{cdev} = K_{cprev} + [\frac{\{i - \Sigma(L_{prev})\}}{L_{stage}}] \times (K_{cnext} \quad K_{cprev}) \text{ ………………. (5)}$$

Where, K_{cdev}iscrop coefficient of rice at crop development stage, i is the day number within the growing season (1……. length of the growing season), L_{stage} is length of the stage under consideration (day),Σ (L_{prev}) is sum of lengths of all previous stages (day), $K_{cnext}$is crop coefficient at the beginning of next stage and $K_{cprev}$is crop coefficient at the end of previous stage.

***Actual crop evapotranspiration*:** Actual crop evapotranspiration was found by multiplying ET_0 by K_c

$$ET_{crop} = K_c \times ET_o \text{ ……………………….. (6)}$$

Where, $ET_{crop}$is actual evapotranspiration (mm/day), K_c is crop coefficient at different growing stages and$ET_0$is reference crop evapotranspiration at different growing stages of rice(mm/day).

Weibull's ranking method was used for probability analysis of 14 years' data (1997-2010). Probability was calculated as follows:

$$P = \frac{m}{N+1} \times 100 \text{ …………………………………(7)}$$

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

The expected rainfall and actual evapotranspiration at probability level of 75% was estimated for different growth stages of BRRI dhan33 and BRRI dhan34 from 1997 to 2010 (14years).

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

SI = Actual evapotranspiration – Rainfall ……(8)

Results and Discussion

***Actual evapotranspiration of BRRI dhan33 and BRRI dhan34 in Bogra district*:** Actual evapotranspiration of BRRI dhan33 and BRRI dhan34 at different growth stages for two transplanting times in Bogra district are given in Table 2 and Table 3, respectively. Actual evapotranspiration of different rice varieties varied due to crop coefficient, reference crop evapotranspiration, length of growing stages and total growing season. In Table 2, the actual evapotranspiration of BRRI dhan33 for the first transplantingtime varied from 27 to 57 mm in initial stage, 99 to 168 mm in crop development stage, 103 to 187 mm in mid stage and 34 to 59 mm in late stage for the second transplantingtime, it varied from 29 to 57 mm in initial stage, 107 to 165 mm in crop development stage, 99 to 165 mm in mid stage and 32 to 46 mm in late stage. In Table 3, actual evapotranspiration of BRRI dhan34 for the first transplantingtime varied from 34 to 52 mm in initial stage, 189 to 250 mm in crop development stage, 99 to 166 mm in mid stage and 16 to 90 mm in late stage for the second transplantingtime, it varied from 37 to 54 mm in initial stage, 192 to 245 mm in crop development stage, 92 to 144 mm in mid stage and 24 to 42 mm in late stage. Higher actual crop evapotranspiration was obtained due to higher values of reference crop evapotranspiration and crop coefficientand the lowest actual crop evapotranspiration was obtained due to lower values of reference crop evapotranspiration and crop coefficient in the said growth stages except initial stage. The highest and lowest actual crop evapotranspiration values were obtained due to higher and lower values of reference crop evapotranspiration in the initial stage.

Table 2. Actual evapotranspiration of BRRI dhan33 in Bogra District for two different transplanting times

Year	**Actual evapotranspiration (mm) at different growth stages of BRRI dhan33**							
	1st transplant				2nd transplant			
	Initial	Crop development	Mid season	Late season	Initial	Crop development	Mid season	Late season
1997	48	159	161	58	56	158	150	45
1998	57	168	187	44	52	134	187	38
1999	41	137	146	59	31	145	137	44
2000	44	154	165	46	46	149	143	39
2001	43	142	156	35	38	137	134	43
2002	39	134	143	44	35	126	123	37
2003	37	127	134	52	46	131	127	41
2004	35	122	131	40	32	152	112	35
2005	34	120	128	28	37	119	122	24
2006	28	100	113	34	29	110	105	33
2007	28	112	120	40	38	134	99	42
2008	27	99	103	34	34	128	142	35
2009	38	132	137	56	27	135	131	42
2010	33	116	124	37	57	165	165	34

Table 3. Actual evapotranspiration of BRRI dhan34 in Bogra Districtfor two different transplanting times

Year	Actual evapotranspiration (mm) at different growth stages of BRRI dhan34							
	1st transplant				2nd transplant			
	Initial	Crop development	Mid season	Late season	Initial	Crop development	Mid season	Late season
1997	51	239	157	47	51	225	136	41
1998	42	250	166	19	54	245	143	42
1999	50	223	154	16	50	212	124	40
2000	48	250	151	60	52	234	139	42
2001	51	243	160	28	49	203	133	39
2002	37	224	150	44	47	192	127	37
2003	42	211	136	46	48	199	139	38
2004	40	207	131	90	45	152	121	35
2005	44	215	141	42	46	186	133	36
2006	38	195	121	70	43	172	119	30
2007	36	188	120	30	42	162	106	24
2008	39	200	125	38	44	175	116	33
2009	34	179	99	6	39	150	98	26
2010	42	189	113	27	37	134	92	32

***Actual evapotranspiration of BRRI dhan33 and BRRI dhan34 in Dinajpur district*:** Actual evapotranspiration of BRRI dhan33 and BRRI dhan34 at different growth stages for transplanting times in Dinajpur district are given in Table 4 and Table 5, respectively. Actual evapotranspiration of different rice varieties varied due to crop coefficient, reference crop evapotranspiration, length of growing stages and total growing season. Actual evapotranspiration of BRRI dhan33 for the first transplanting time varied from 26 to 55 mm in initial stage, 83 to 157 mm in crop development stage, 94 to 163 mm in mid stage and 31 to 50 mm in late stage (Table 4). For the second transplanting time, it varied from 26 to 52 mm in initial stage, 75 to 139 mm in crop development stage, 75 to 127 mm in mid stage and 13 to 29 mm in late stage. Actual evapotranspiration of BRRI dhan34 at the first transplanting time varied from 30 to 48 mm in initial stage, 131 to 223 mm in crop development stage, 78 to 138 mm in mid stage and 23 to 40 mm in late stage (Table 5). For the second transplanting time, it varied from 28to 52 mm in initial stage, 127 to 230 mm in crop development stage, 92 to 129 mm in mid stage and 35 to 45 mm in late stage. Higher actual crop evapotranspiration was obtained due to higher values of reference crop evapotranspiration and crop coefficient and lowest actual crop evapotranspiration was obtained due to lower values of reference crop evapotranspiration and crop coefficient in the said growth stages except initial stage.

***Supplemental irrigation in Bogra District*:** The deficiency of water at different growing stages of BRRI dhan33 and BRRI dhan34 for Bogra district is provided in the Table 6 and Table 7, respectively. For BRRI dhan33 (Table 6), based on dependable rainfall and actual crop evapotranspiration at 75% probability level, the deficiency of water occurred during the mid-stage and late stage for 1st transplanting time (Figure 1), and development stage, mid stage and late stage for the 2nd transplanting time (Figure 2).

Table 4. Actual evapotranspiration of BRRI dhan33 in Dinajpur Districtfor two different transplanting times

Year	Actual evapotranspiration (mm) at different growth stages of BRRI dhan33							
	1st transplant				2nd transplant			
	Initial	Crop development	Mid season	Late season	Initial	Crop development	Mid season	Late season
1997	55	149	148	50	46	121	113	27
1998	50	137	140	44	51	138	127	29
1999	56	156	163	34	33	120	112	25
2000	37	134	137	43	37	114	107	24
2001	52	142	142	48	33	108	98	23
2002	33	144	155	39	51	126	124	28
2003	53	130	131	23	33	104	97	22
2004	31	127	125	47	26	88	75	18
2005	38	112	120	40	32	98	89	20
2006	30	123	113	32	21	92	80	17
2007	29	145	120	27	31	92	89	18
2008	21	123	110	36	26	75	69	13
2009	32	96	106	36	32	104	92	20
2010	26	83	94	24	40	118	118	26

Table 5. Actual evapotranspiration of BRRI dhan34 in Dinajpur Districtfor two different transplanting times

Year	Actual evapotranspiration (mm) at different growth stages of BRRI dhan34							
	1st transplant				2nd transplant			
	Initial	Crop development	Mid season	Late season	Initial	Crop development	Mid season	Late season
1997	47	223	108	38	51	211	124	33
1998	46	212	106	37	46	195	118	42
1999	45	205	104	36	51	202	121	42
2000	48	237	130	40	44	175	110	39
2001	42	187	98	32	45	182	124	41
2002	44	197	99	34	46	191	117	32
2003	42	182	96	23	43	171	110	39
2004	38	173	95	31	41	165	108	31
2005	37	159	91	22	30	156	112	37
2006	38	167	95	30	36	162	104	29
2007	37	141	83	24	28	141	91	36
2008	49	248	138	42	41	127	92	30
2009	30	131	78	23	33	147	100	36
2010	37	148	87	25	52	230	129	45

Similarly, the water deficiency period for BRRI dhan34 (Table 7) was detected as mid stage and late stage for 1st transplanting (Figure 3) and 2nd transplanting time (Figure 4). The shortage of rainfall was responsible for deficiency of water. Hence, in this deficiency period, irrigation is essential for successful crop production.

Table 6. Supplemental irrigation for BRRI dhan33 in Bogra District (rainfall and ET_c at 75% probability level) for two different transplanting times

Stage	BRRI dhan33							
	1st transplant				2nd transplant			
	R.f* (mm)	ET_c* (mm)	S.I* (mm)	Remarks	R.f (mm)	ET_c (mm)	S.I (mm)	Remarks
Establishment stage	52	42	–	No need of irrigation	102	32	–	No need of irrigation
Development stage	128	110	–	No need of irrigation	87	98	11	Irrigation is needed
Mid stage	102	129	27	Irrigation is needed	83	123	42	Irrigation is needed
Late stage	32	42	12	Irrigation is needed	0	39	39	Irrigation is needed

*R.f –Rainfall, ET_c–Actual crop evapotranspiration, S.I – Supplemental irrigation

Table 7. Supplemental irrigation for BRRI dhan34 in Bogra District (rainfall and ET_c at 75% probability level)for two different transplanting times

Stage	BRRI dhan34							
	1st transplant				2nd transplant			
	R.f* (mm)	ET_c* (mm)	S.I* (mm)	Remarks	R.f (mm)	ET_c (mm)	S.I (mm)	Remarks
Establishment stage	60	34	–	No need of irrigation	55	39	–	No need of irrigation
Development stage	193	177	–	No need of irrigation	223	161	–	No need of irrigation
Mid stage	47	113	66	Irrigation is needed	68	102	34	Irrigation is needed
Late stage	0	18	18	Irrigation is needed	0	32	32	Irrigation is needed

*R.f –Rainfall, ET_c–Actual crop evapotranspiration, S.I – Supplemental irrigation

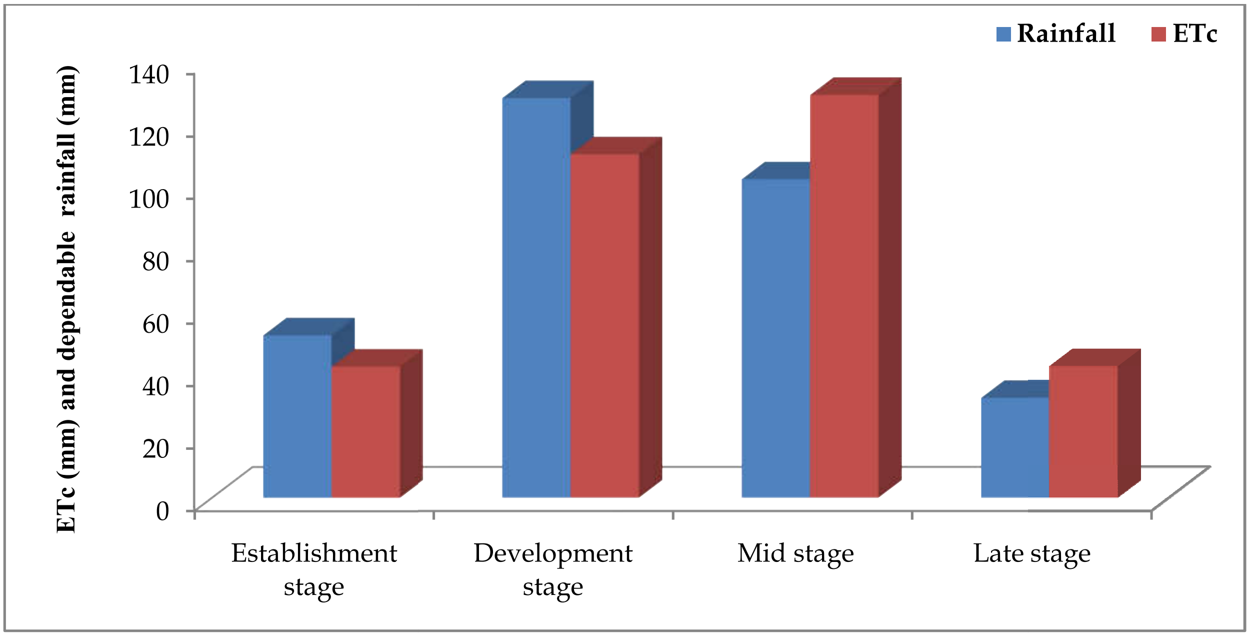

Figure 1. Dependable rainfall at 75% probability as compared to ET_cat initial, development, mid and late stages of BRRI dhan33 for 1st transplanting time in Bogra district

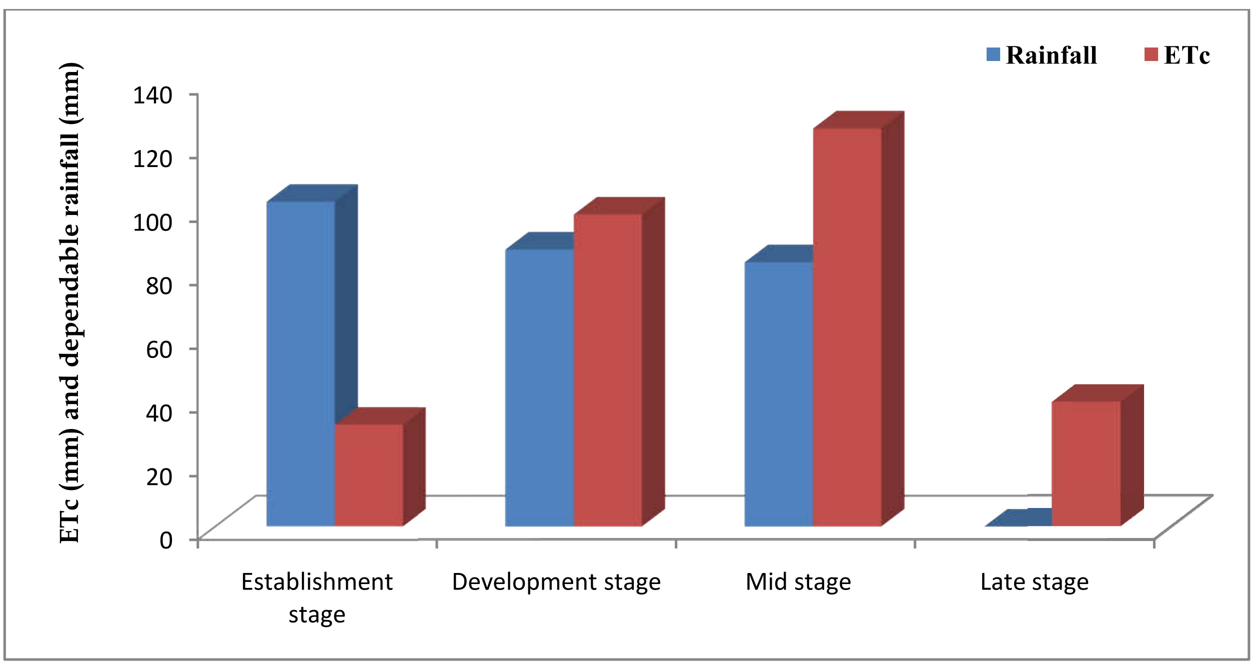

Figure 2. Dependable rainfall at 75% probability as compared to ET_cat initial, development, mid and late stages of BRRI dhan33 for 2nd transplanting time in Bogra district

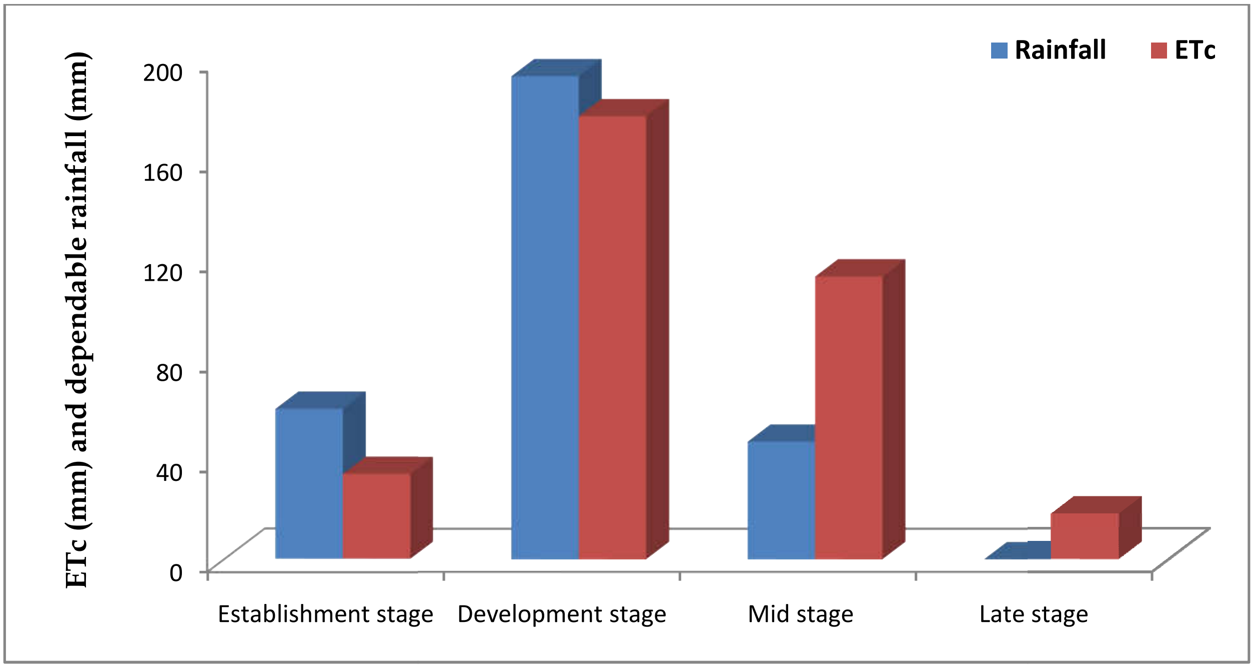

Figure 3. Dependable rainfall at 75% probability as compared to ET_catinitial, development, mid and late stages of BRRI dhan34 for 1st transplanting time in Bogra district

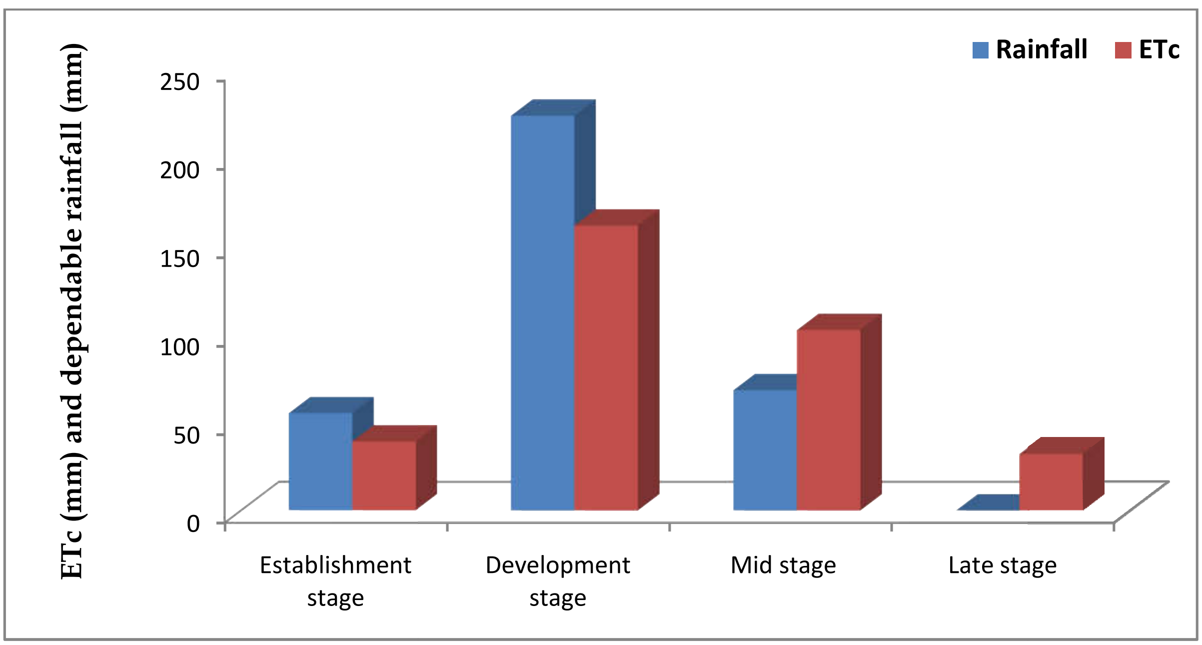

Figure 4. Dependable rainfall at 75% probability as compared to ET_catinitial, development, mid and late stages of BRRI dhan34 for 2nd transplanting time in Bogra district

***Supplemental irrigation in Dinajpur District*:** The deficiency of water at different growing stages of BRRI dhan33 and BRRI dhan34 for Dinajpur district is given in Table 8 and Table 9, respectively.

Table 8. Supplemental irrigation for BRRI dhan33 in Dinajpur District (Rainfall and ET_c at 75% probability level)for two different transplanting times

Stage	BRRI dhan33							
	1st transplant				2nd transplant			
	R.f* (mm)	ET_c* (mm)	S.I* (mm)	Remarks	R.f (mm)	ET_c (mm)	S.I (mm)	Remarks
Establishment stage	50	30	_	No need of irrigation	100	38	_	No need of irrigation
Development stage	130	120	_	No need of irrigation	95	105	_	No need of irrigation
Mid stage	123	130	7	Irrigation is needed	19	121	102	Irrigation is needed
Late stage	15	46	31	Irrigation is needed	0	30	30	Irrigation is needed

*R.f –Rainfall, ET_c–Actual crop evapotranspiration, S.I – Supplemental irrigation

Table 9. Supplemental irrigation for BRRI dhan34 in Dinajpur District (Rainfall and ET_c at 75% probability level)for two different transplanting times

Stage	BRRI dhan34							
	1st transplant				2nd transplant			
	R.f* (mm)	ET_c* (mm)	S.I* (mm)	Remarks	R.f (mm)	ET_c (mm)	S.I (mm)	Remarks
Establishment stage	50	42	_	No need of irrigation	25	38	13	Irrigation is needed
Development stage	122	188	66	Irrigation is needed	306	169	_	No need of irrigation
Mid stage	120	99	_	No need of irrigation	105	121	16	Irrigation is needed
Late stage	0	34	34	Irrigation is needed	0	32	32	Irrigation is needed

*R.f –Rainfall, ET_c–Actual crop evapotranspiration, S.I – Supplemental irrigation

For BRRI dhan33 (Table 8), based on dependable rainfall and actual crop evapotranspiration at 75% probability level, the deficiency of water occurred during the mid-stage and late stage for 1st(Figure 5)and 2ndtransplanting time(Figure 6). Similarly, the water deficiency period for BRRI dhan34 (Table 9) was detected as development stage and late stage for 1st transplanting (Figure 7) and development stage for 2nd transplanting time (Figure 8). About 80% of the total rainfall occurred during the monsoon period. The monsoon season starts mainly in the June and continues up to October. Hence, it is observed that the water deficiency mainly occurred after the October in the mid stage and late stage. Proper arrangement of supplemental irrigation can bring successful rice production.

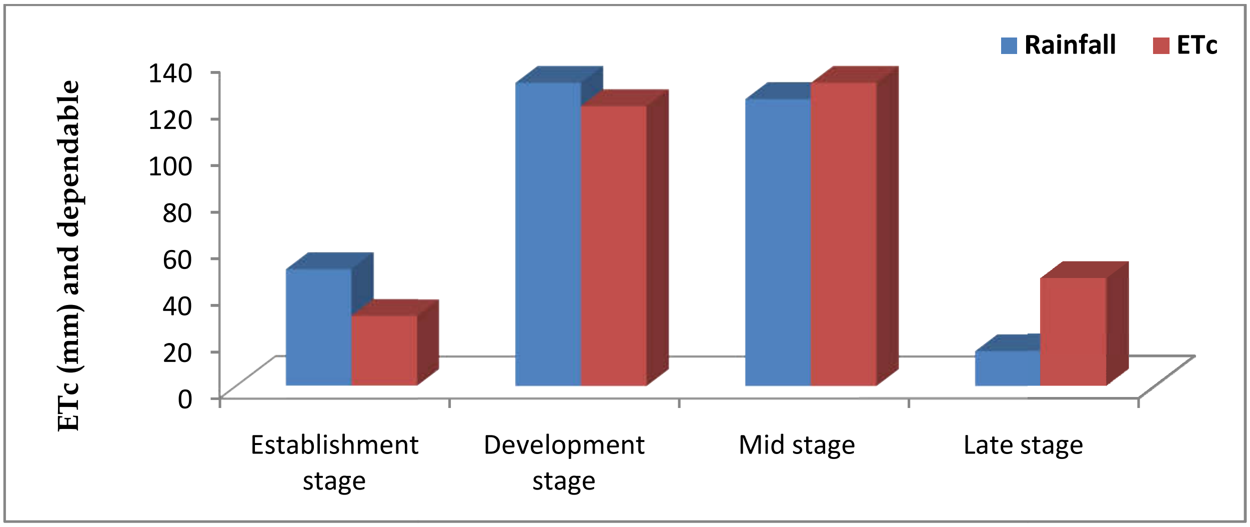

Figure 5. Dependable rainfall at 75% probability as compared to ET_catinitial, development, mid and late stages of BRRI dhan33 for 1st transplanting time in Dinajpur district

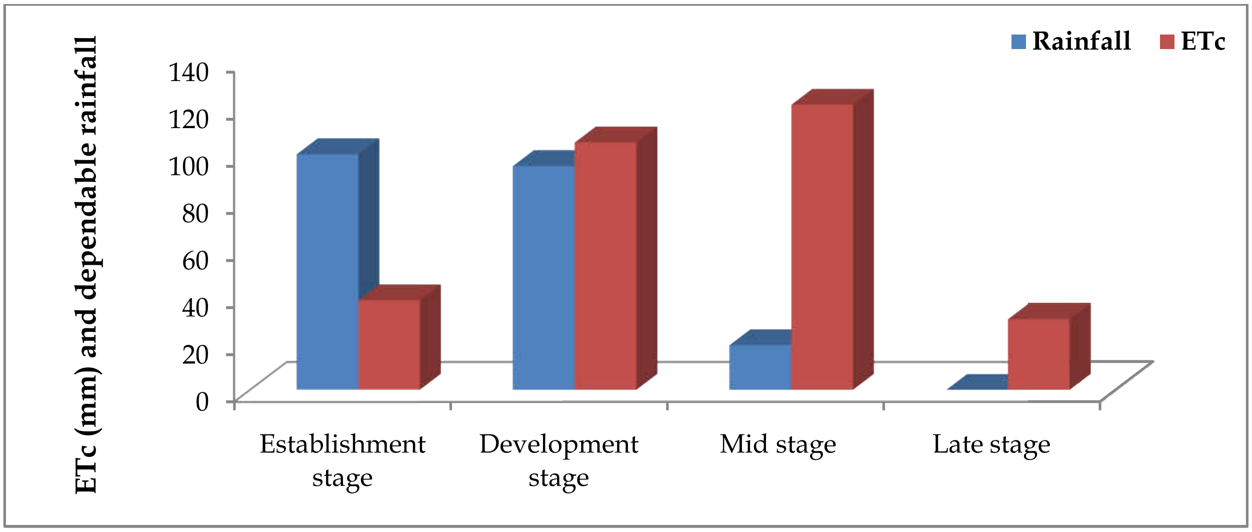

Figure 6. Dependable rainfall at 75% probability as compared to ET_catinitial, development, mid and late stages of BRRI dhan33 for 2nd transplanting time in Dinajpur district

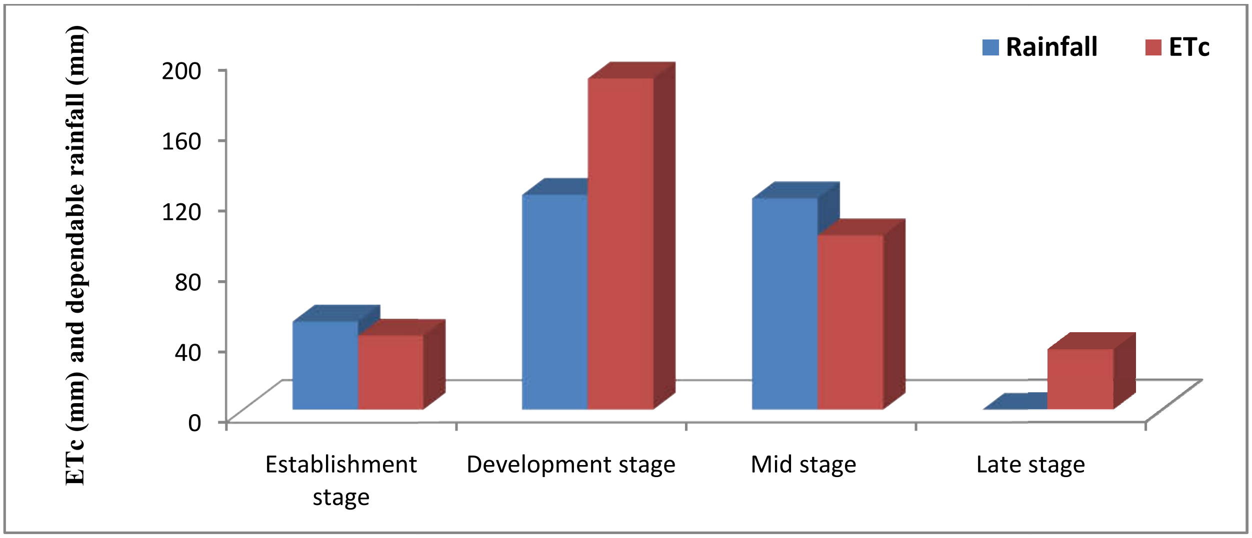

Figure 7. Dependable rainfall at 75% probability as compared to ET_catinitial, development, mid and late stages of BRRI dhan34 for 1st transplanting time in Dinajpur district

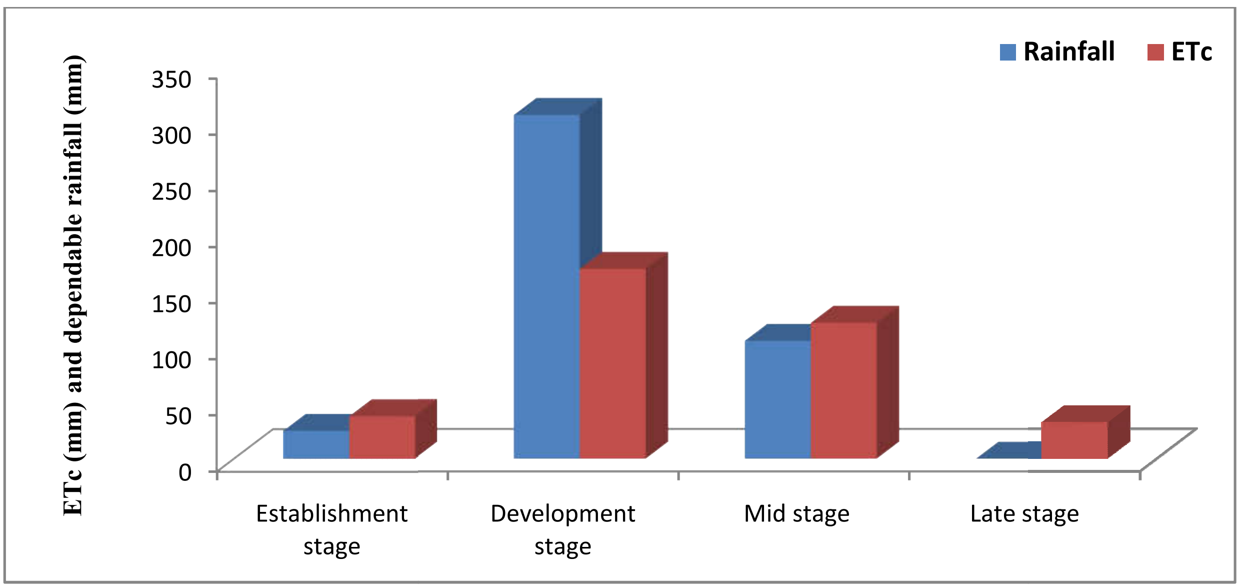

Figure 8. Dependable rainfall at 75% probability as compared to ET_catinitial, development, mid and late stages of BRRI dhan34 for 2nd transplanting time in Dinajpur district

Conclusions

Actual crop evapotranspiration, ET_C, of BRRI dhan33 for 1st transplanting time varied from 263 to 461 mm and 234 to 425 mm in Bogra and Dinajpur districts, respectively. For BRRI dhan34, the variations of ET_c in Bogra and Dinajpur districts were 318 to 509 mm and 262 to 477 mm, respectively for 1st transplanting time. In Bogra district, there was mostly decreasing trend of rainfall during the rice growing period. But, for

Dinajpur district, there was mostly increasing trend of rainfall during the growing period. For BRRI dhan33, supplemental irrigation was needed mainly in mid and late stages for both districts. For BRRI dhan34, supplemental irrigation was needed in development, mid and late stages for both districts.

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