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Estimation of actual crop evapotranspiration and supplemental irrigation for Aman rice cultivation in the northern part of Bangladesh

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ABSTRACT

The study was conducted to estimate the trend of actual crop water requirement and supplemental irrigation needed for a popular high yielding aman rice variety, *i.e.*, BR11 grown in Rajshahi and Rangpur districts of northern Bangladesh. The FAO Penman-Monteith method was used to estimate the reference crop evapotranspiration (ET_0) at four different growth stages of rice. The actual evapotranspiration (ET_c) of BR11 rice variety at different growth stages was estimated, and its trend along with that of rainfall was analyzed. The Weibull's method was employed for performing probability analysis, and the dependable rainfall and ET_c at 75% probability level was determined for two different transplanting times and four different growth stages of BR11 for 20 years. It was observed that the rainfall and ET_c for the two different transplanting times of BR11 rice varied over the whole growing season in both the districts. After performing the analysis of probability, the supplemental irrigation (SI) was computed for BR11 in both the districts. The study revealed that the SI was required in late-stage for Rajshahi district but, for Rangpur district, it was required in both mid and late stages. The results would be helpful for decision makers as well as for farmers to use water efficiently by understanding the need for ET_c and SI for BR11 aman rice cultivation in Bangladesh.

Keywords: Actual evapotranspiration, crop coefficient, rainfall, supplemental irrigation, aman rice

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1 Introduction

Climate change is being considered as the most dangerous environmental warning of the 21st century and Bangladesh suffers a lot of consequences of changing climate. Any change in hydrologic components will have a significant negative impact on Bangladesh economy (OECD, 2003). It is forecasted that climatic variability could have a dangerous impact on agriculture which is a vital economic factor in Bangladesh, accounting for about 20% of the GDP and 65% of the labor force (Eitzinger and Kubu, 2009). In Bangladesh, the yearly rainfall varies from 2300 to 2600 mm, but its distribution is irregular. The average annual rainfall in the country was 2486 mm, and from June to September month, about 70 - 80% of the total rainfall occurred (Ali et al., 2007; Sen et al., 2017). The efficacy of rainfall for crop production is dependent on its adequacy, certainty and distribution. Even under improved management practices, most of the variation in crop yield can be explained by the use of analysis of weather elements. (Vishwakarma et al., 2000; Akter et al., 2013). Due to the drastic changes in climate, the rainfall pattern may be changed, again uncertainty in spatio-temporal distribution of rainfall, existing rain-fed agriculture, whatever its scale partial or full coverage, will be transformed into entirely groundwater dependent irrigation agriculture in the near future The uncertainty of rainfall pattern will also increase occurrences of climate-induced calamities like floods, droughts, heat waves and cyclones in future (FAO, 2006; IPCC, 2007). These issues create a great concern about the drastic consequences on the reduction of crop productivity globally, especially in developing countries. Under this context of erratic rainfall pattern as the consequence of climate change, supplemental irrigation, application of a limited quantity of water to the rain-fed crops if rainfall fails to deliver enough moisture for normal crop growth, is considered to be very effective (FAO, 2007; IPCC, 2007; Roudier et al., 2011).

One of the main components of an agricultural land's water balance is evapotranspiration (Yarahmadi, 2003; Anda et al., 2015; Güçlü et al., 2017), which has utmost importance for agricultural water resources management (Blanka et al., 2017). Application of too high or too less amount of water at the wrong stage of crop development can hamper the crop growth and reduce its yield. For the environmental threats on water, the evapotranspiration rate needs to be estimated regionally to know the water requirement for the effective management of the national water demands. On the contrary, rainfall is one of the leading climatic parameters to affect crop production. Aman is a rain-fed rice growing in the monsoon season, but it may require supplemental irrigation at the time of planting and, often, in the time of the flowering stage, due to inadequate rainfall (BRRI, 1991). It would be able to optimize the use of water by knowing the crop-water requirement effectively. Supplemental irrigation if applied at the time of the critical stages of crop growth can make a substantial improvement in crop yield and water productivity. Therefore, during dry spells, supplemental irrigation is an effective approach to remove the adverse effect of soil moisture stress in rain-fed crops.

To our knowledge, a few research works have been conducted on the estimation of actual crop evapotranspiration and supplemental irrigation for rice cultivation in Bangladesh context. Sen et al. (2017) carried out a study to evaluate the supplemental irrigation requirement for proper planning of aman rice cultivation in Bogra and Dinajpur districts of Bangladesh. Fahmida et al. (2017) conducted a study to estimate the actual crop evapotranspiration and dependable rainfall for beneficial planning of two aman rice varieties *i.e.*, BR11 and BR22 cultivation in Dinajpur district of Bangladesh, where they found that the supplemental irrigation was required in the development, mid and late stages for BR11, but in the case of BR22, it was needed for mid and late stages. Their findings demonstrate that the time and amount of supplemental irrigation are not the same for all regions rather vary from one region to another. In the drought-prone areas, for instance - Rajshahi and Rangpur districts of Bangladesh, specific research work relating the actual crop water and supplemental irrigation water demand of rice has not been conducted yet. Therefore, an attempt was taken to find out the trend of actual water requirement of aman rice variety for specifying the increasing or decreasing trend of water and to estimate the supplemental irrigation needed at four different growth stages of aman rice variety BR11 in Rajshahi and Rangpur districts of Bangladesh.

2 Materials and Methods

2.1 Data collection

The study was conducted in two districts of the northern part of Bangladesh, namely, Rajshahi and Rangpur to evaluate the trend of actual evapotranspiration and to know the supplemental irrigation of BR11 aman rice variety. Climatic data such as daily rainfall, daily maximum and minimum temperature, relative humidity, wind speed and sunshine hour were collected for a period of 20 yr (1991 - 2010) from the two weather stations of Rajshahi and Rangpur districts, Bangladesh Meteorological Department (BMD), Bangladesh. High yielding aman rice variety BR11 was used as the planting material in this study. This variety, released by Bangladesh Rice Research Institute (BRRI) in 1980, is on average 115 cm tall, takes approximate 145 d to mature, transplanted between mid-June and mid-July, and harvested between late October and late November (BRRI, 2006). The duration of different growth stages of the BR11 aman rice is given in Fig. 1.

2.2 Interpretation of missing data

The simple arithmetic mean method (Patra, 2001) was employed to estimate some rainfall data which were

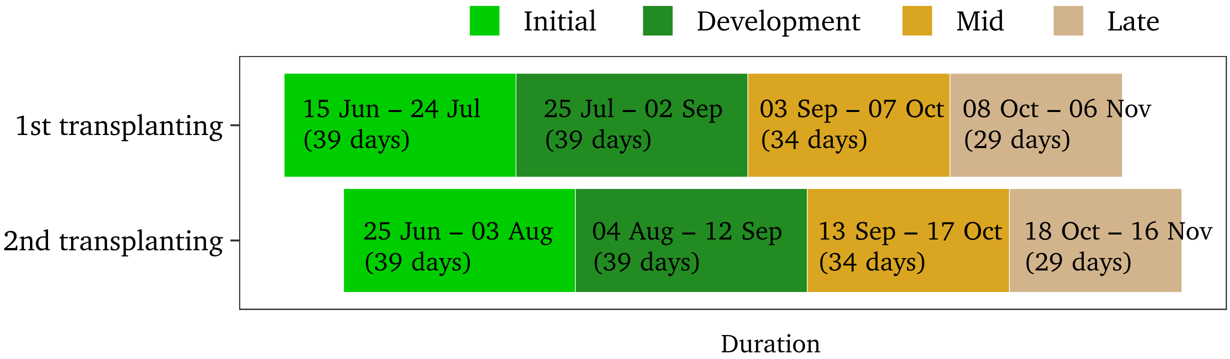

Figure 1. Time length of different growth stages of BR11 aman rice for different transplanting times

found partially missing.

$$P_x = \frac{P_1 + P_2 + ... + P_n}{n} \tag{1}$$

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

2.3 Estimation of reference crop evapotranspiration (ET_0)

The reference crop evapotranspiration (ET_0) was estimated by employing the Penman-Monteith method, referred to as a standard method by FAO (Allen et al., 1998).

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

where, ET_0 is reference crop evapotranspiration (mm d^{-1}), R_n is net radiation at the surface of the crop (MJ m^2 d^{-1}), G is the density of soil heat flux (MJ m^2 d^{-1}), T is air temperature at 2 m height (°C), u_2 is wind speed at 2 m height (m s^{-1}), *es* is saturation vapor pressure (kPa), *ea* is actual vapor pressure (kPa), $(es - ea)$ is the saturation vapor pressure deficit of the air (kPa), $|delta$ is slope of saturation vapor pressure and temperature relationship curve (kPa per °C) and γ is psychometric constant (kPa per °C).

2.4 Estimation of crop coefficient (K_c)

The growing period of rice has four different growth stages, such as initial, crop development, mid-season and late season. The crop coefficient (K_c) of rice was considered as 1.05 for the initial growth stage (FAO, 2006). The crop coefficient at mid-stage is estimated by the following equation (Allen et al., 1998):

$$K_{c\text{mid}} = 1.20 + [0.04(u_2 - 2) - 0.004(\text{RH}_{\text{min}} - 45)](\frac{h}{3})^3 \tag{3}$$

where, $K_{c\text{mid}}$ is crop coefficient of rice for the mid-season growth stage, u_2 is mean daily wind speed at 2 m height over growing crops (m s^{-1}), RH$_{min}$ is mean daily minimum relative humidity (%), and h is the mean plant height during the mid-season growth stage (m).

Similarly, the crop coefficient at late-season growth stage is estimated by the following equation (Allen et al., 1998):

$$K_{c\text{end}} = 1.20 + [0.04(u_2 - 2) - 0.004(\text{RH}_{\text{min}} - 45)](\frac{h}{3})^3 \tag{4}$$

where, $K_{c\text{end}}$ is crop coefficient of rice for the mid-season growth stage, u_2 is mean daily wind speed at 2 m height over growing crops (m s^{-1}), RH$_{min}$ is mean daily minimum relative humidity (%), and h is the mean plant height during the mid-season growth stage (m).

Finally, the crop coefficient at the crop development stage is calculated by the following formula (Allen et al., 1998):

$$K_{c\text{dev}} = K_{c\text{prev}} + \left[\frac{i - \sum L_{\text{prev}}}{L_{\text{stage}}}\right] \times (K_{c\text{next}} - K_{c\text{prev}}) \tag{5}$$

where, $K_{c\text{dev}}$ is a crop coefficient of rice at the crop development stage, i is the number of days within the growing season of rice, L_{stage} is the length of the stage under consideration (d), $\sum L_{\text{prev}}$ is the sum of lengths of all previous stages (d), $K_{c\text{next}}$ is a crop coefficient of rice at the beginning of the next stage and $K_{c\text{prev}}$ is a crop coefficient of rice at the end of the previous stage.

2.5 Estimation of actual crop evapotranspiration (ET_c) and supplemental irrigation

More precise estimation of actual crop evapotranspiration (ET_c) in a regional scale has always been one of the most critical challenges (Taherparvar and Pirmoradian, 2018). The ET_c was estimated multiplying ET_0 by K_c (Jensen et al., 1990; Allen et al., 1998).

$$ET_c = K_c \times ET_0 \tag{6}$$

where, ET_c is actual crop evapotranspiration (mm d^{-1}), K_c is a crop coefficient at different growing stages of rice and ET_0 is reference crop evapotranspiration at different growing stages of rice (mm d^{-1}).

The probability analysis of 20-years' data (1991 - 2010) was done by employing the Weibull's ranking method (Raghunath, 2006).

$$P = \frac{m}{N+1} \times 100$$

where, P is the probability level, N is the total number of data and m is the rank of the data based on descending order.

At a probability level of 75%, the dependable rainfall and actual crop evapotranspiration were estimated for four different growth stages of BR11 from 1991 to 2010 (20 yr). The supplemental irrigation (SI) at four different growth stages of aman rice under Rajshahi and Rangpur districts was estimated based on the amount of dependable rainfall (R_f) and actual crop evapotranspiration (ET_c) at a probability level of 75%. In this case, if $R_f > ET_c$, no need for SI and on the contrary, if $R_f < ET_c$, SI is needed for the rice cultivation.

2.6 Trend of ET_c and rainfall

The trend of actual crop evapotranspiration and rainfall during four different growth stages of BR11 in Rajshahi and Rangpur districts were evaluated for understanding the water demand of the variety. The MAKESENS trend model was used in this case. The trend model was developed using Microsoft Excel 97 and macros coded with Microsoft Visual Basic (Salmi et al., 2002). By knowing the trend of actual evapotranspiration and rainfall, it is possible to say the present condition of crop water requirement.

3 Results and Discussion

3.1 Variation of crop coefficients (K_c)

Calculated crop coefficients (K_c) of BR11 aman rice in Rajshahi and Rangpur districts are given in Table 1. The crop coefficients of the rice variety at four different growth stages in aman season varied in different years and with the time of transplanting. In Rajshahi district, the K_c of BR11 varied from 1.03 to 1.09, 1.15 to 1.22, 0.83 to 0.90 for the crop development, mid-season and late-season growth stages, respectively in the first/earlier transplanting time, and in case of the second transplanting time, K_c varied from 1.02 to 1.10 in the crop development stage, 1.13 to 1.23 in the mid-stage, 0.81 to 0.93 in the late stage. In Rangpur district, the K_c of BR11 varied from 1.01 to 1.08, 1.15 to 1.26, 0.83 to 0.91 for the crop development, mid-season and late-season growth stages, respectively in the first transplanting time, and in case of the second transplanting time, K_c varied from 1.01 to 1.10 in the crop development stage, 1.13 to 1.23 in the mid-stage, 0.81 to 0.93 in the late stage. On an average, the highest K_c value of 1.21 was found at the mid-stage for the first transplanting time in Rangpur, and the lowest (0.85) was found at the late stage for the second transplanting time in Rajshahi, presented in Table 1.

3.2 Actual evapotranspiration (ET_c)

Actual evapotranspiration (ET_c) of BR11 at four different growth stages for two transplanting times in Rajshahi and Rangpur districts is presented in Table 1. The ET_c of the rice variety differed due to the values of K_c, ET_0, length of growth stages and total growing season. In Rajshahi, the ET_c of BR11 at the first transplanting time ranged from 31 to 50 mm in the initial growth stage, 111 to 193 mm in the crop development stage, 85 to 142 mm in the mid-stage and 20 to 59 mm in the late-stage, and at the second transplanting time, it varied from 31 to 49 mm in the initial growth stage, 120 to 190 mm in the crop development stage, 85 to 142 mm in the mid-stage and 33 to 60 mm in the late-stage.

In Rangpur district, the ET_c of BR11 at the first transplanting time ranged from 26 to 56 mm in the initial growth stage, 122 to 196 mm in the crop development stage, 98 to 140 mm in the mid-stage and 43 to 60 mm in the late-stage, and at the second transplanting time, it ranged from 36 to 54 mm in the initial growth stage, 114 to 194 mm in the crop development stage, 98 to 142 mm in the mid-stage and 39 to 62 mm in the late-stage. On an average, the highest value of ET_c of 158.2 mm was at the crop development stage for the first transplanting time in Rangpur, and the lowest of 38.55 mm was at the initial stage for the first transplanting time in Rajshahi, presented in Table 1. Higher ET_c was obtained due to the higher values of K_c and ET_0, and the lower ET_c was obtained due to the lower values of K_c and ET_0 in the growth stages except for the initial growth stage. On the contrary, the highest and lowest ET_c values were obtained due to higher and lower values of ET_0 in the initial growth stage of rice. The present findings of ET_c in four different growth stages of aman rice agreed with those of Sen et al. (2017) who conducted a study to assess the ET_c for successful planning of aman rice cultivation

Table 1. Crop coefficients and actual evapotranspiration of BR11 in aman season in Rajshahi and Rangpur districts for the period of 1991–2010

Districts		First transplanting				Second transplanting			
		Initial stage	Develop. stage	Mid stage	Late stage	Initial stage	Develop. stage	Mid stage	Late stage
	Crop coefficients (K_c)								
Rajshahi	Range	1.05	1.03–1.09	1.15–1.22	0.83–0.90	1.05	1.02–1.1	1.13–1.23	0.81–0.93
	Average	1.05	1.07	1.2	0.87	1.05	1.06	1.19	0.85
	SD	0	0.02	0.02	0.02	0	0.03	0.03	0.04
Rangpur	Range	1.05	1.01–1.08	1.15–1.26	0.83–0.91	1.05	1.01–1.1	1.13–1.23	0.81–0.93
	Average	1.05	1.04	1.21	0.88	1.05	1.03	1.18	0.86
	SD	0	0.03	0.03	0.03	0	0.03	0.04	0.04
	Actual evapotranspiration (ET_c) (mm)								
Rajshahi	Range	31-50	111–193	74–166	20–59	31–49	120–190	71–142	30–60
	Average	38.55	155.75	122.3	44.4	41.25	153.65	109.3	46.65
	SD	5.64	21.37	23.42	11.86	4.63	18.34	18.82	7.32
Rangpur	Range	26–56	112–200	98–149	34–60	34–53	114–194	98–142	39–62
	Average	39.8	158.2	123.25	49.9	43.35	153.9	122.9	48.5
	SD	8.13	24.18	12.93	7.71	5.11	20.67	12.31	6.66

in Bogra and Dinajpur districts of Bangladesh.

3.3 Trends of ET_c and rainfall

The trends of actual evapotranspiration and rainfall for the first and second transplanting times of BR11 in Rajshahi and Rangpur districts are shown in Figs. 2 and 3. The trend of actual crop evapotranspiration in Rajshahi district for BR11 rice variety was increasing but in Rangpur district, it was decreasing mostly except in mid-stage of first transplanting time. The trend of rainfall in Rajshahi district was increasing mostly except in late-stage for BR11 rice variety. But in Rangpur district, the trend of rainfall is decreasing in the mid and late stage for the first and second transplanting times.

3.4 Supplemental irrigation

The shortage of water at four different growing stages of BR11 in Rajshahi and Rangpur districts is presented in Table 2. Based on the dependable rainfall and ET_c at a probability level of 75%, the deficiency of water was observed during the late stage for both in the first and second transplanting times of BR11 in Rajshahi district. Similarly, the water deficiency period for BR11 in Rangpur district was found during mid and late stages for both in the first and second transplanting times. The deficiency of water for the rice cultivation was occurred due to the shortage of rainfall. Hence, in this deficiency period, supplemental irrigation is essential for successful crop growth with better production. The present findings of the study on supplemental irrigation for BR11 in Rangpur District for two different transplanting times are in agreement with Sen et al. (2017), who found that the supplemental irrigation was required in the mid and late growth stages for aman rice cultivation in Bogra district of Bangladesh for the two different transplanting times.

4 Conclusions

The crop coefficients of BR11 aman rice variety at four different growth stages for the two different transplanting times were varied due to the change in relative humidity and wind speed. The actual crop evapotranspiration (ET_c) of BR11 rice variety for the first transplanting time was ranged from 250 to 468 mm and 279 to 465 mm in Rajshahi and Rangpur districts, respectively. A mostly increasing trend of rainfall and decreasing trend of ET_c was found in this study. For BR11, supplemental irrigation was required in only late-stage for Rajshahi district but, for Rangpur district, it was required in mid and late stages for the two different transplanting times. Therefore, it can be concluded that the findings from the study would be very much useful for the farmers to utilize water efficiently for BR11 aman rice cultivation in Bangladesh, based on the knowledge of the need of actual crop evapotranspiration and supplemental irrigation.

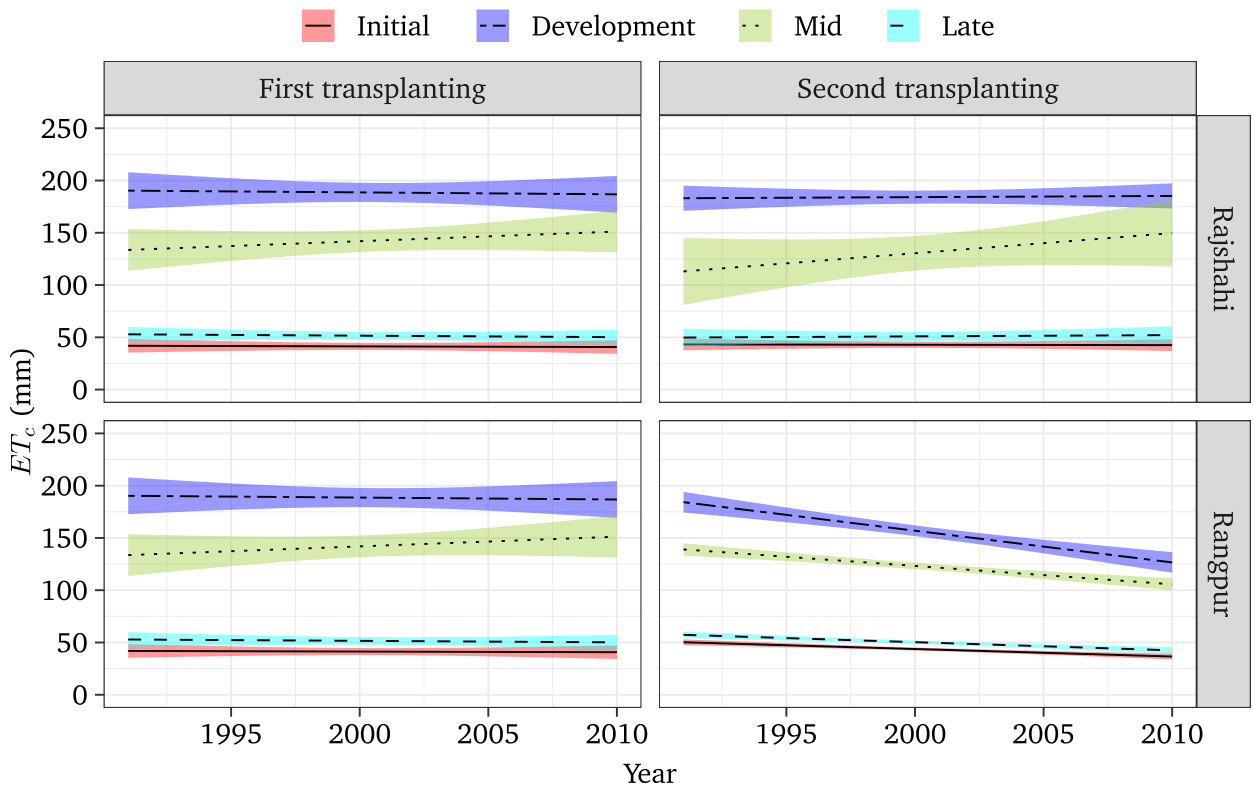

Figure 2. Trend of actual evapotranspiration for first and second transplanting time of BR11 in Rajshahi and Rangpur districts for the period of 1991–2010. Shaded ribbons associated with the trend lines designate the respective standard error region.

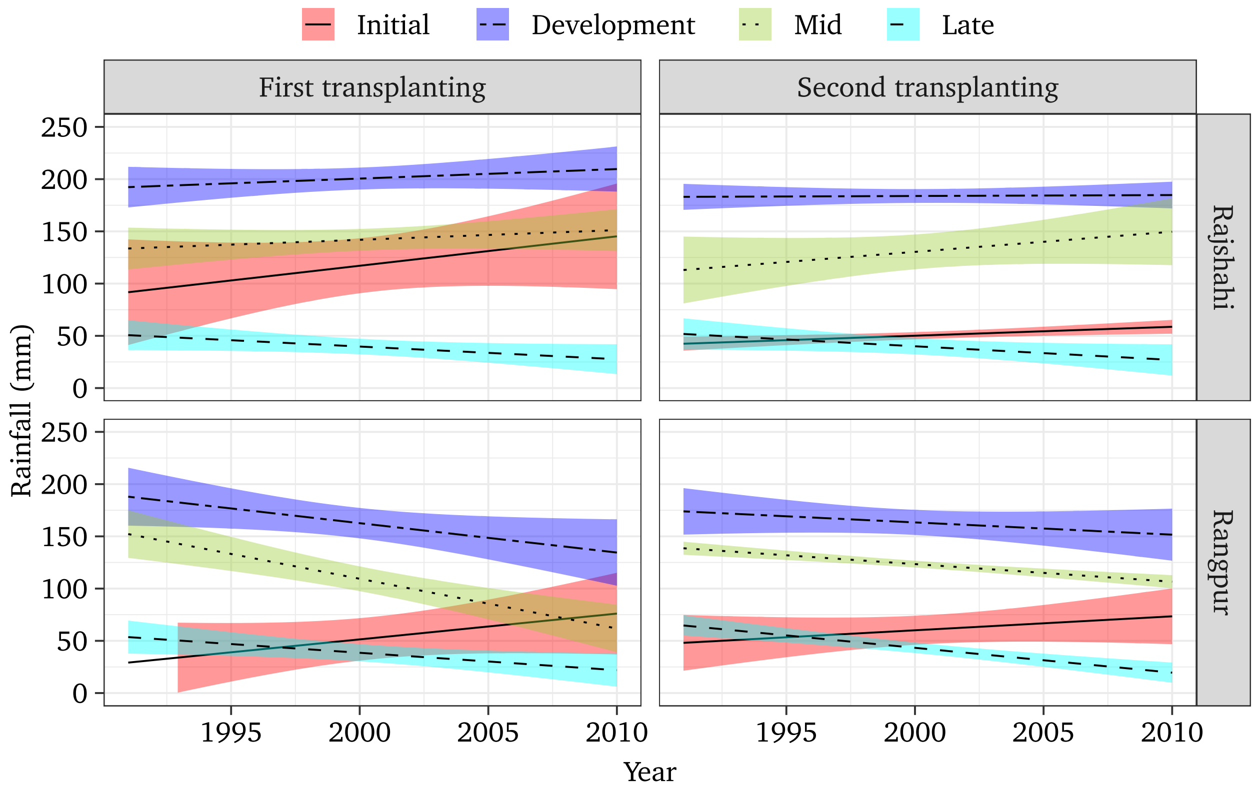

Figure 3. Trend of rainfall for first and second transplanting time of BR11 in Rajshahi and Rangpur districts for the period of 1991–2010. Shaded ribbons associated with the trend lines designate the respective standard error region.

Table 2. Supplemental irrigation for BR11 in Rajshahi and Rangpur districts (rainfall and ET_c at 75% probability level) for two different transplanting times

Districts	Stage	First transplanting				Second transplanting			
		R_f (mm)	ET_c (mm)	SI (mm)	Irrigation needed?	R_f (mm)	ET_c (mm)	SI (mm)	Irrigation needed?
Rajshahi	Establishment	80	40	–	No	70	49	–	No
	Development	212	156	–	No	273	149	–	No
	Mid	253	153	–	No	175	126	–	No
	Late	40	47	7	Yes	10	48	38	Yes
Rangpur	Establishment	20	30	–	No	20	46	–	No
	Development	222	160	–	No	163	166	–	No
	Mid	70	126	56	Yes	78	113	35	Yes
	Late	33	52	19	Yes	0	52	52	Yes

R_f = dependable rainfall , ET_c = actual evapotranspiration, and SI = supplemental irrigation

Conflict of Interest

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

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