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Early transplanting of rainfed rice minimizes irrigation demand by utilizing rainfall

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Abstract

Background: Rainfall is the key contributor to provide soil moisture for wet season rice (T. Aman) cultivation. Erratic rainfall often causes water shortage resulting negative impact on plant growth and grain yield. The study aimed to determine suitable transplanting window that utilize maximum rainfall for T. Aman rice. Firstly, three years field experiment were conducted in Kushtia, Bangladesh from T. Aman, 2013 to 2015, and then the findings were implemented for another two adjacent locations, Panba and Rajshahi. The field experiment considered six transplanting dates of popular cultivar BR11 (growth duration 145 days) at 7 days interval starting from 10 July to 14 August. The CROPWAT 8.0 model was used to calculate crop water requirement (CWR), effective rainfall and irrigation demand (ID) from collected weather data in each growth phase of rice.

Results: In all locations T. Aman rice received enormous rainfall up to vegetative phase resulting no irrigation demand in all three tested years. The early transplanting received more rainfall in reproductive phase than late planting. Thus, Irrigation demand increased at reproductive phase with delay transplanting in moderate drought prone Kushtia, Pabna and Rajshahi. A significant relationship ($R^2 = 0.71$) observed between reproductive phase ID and grain yield, while grain yield responded weakly with the ID at ripening phase. Based on yield performance 10–24 July found suitable transplanting window for BR11 in Kushtia. Considering the relationship between ID and grain yield, 10–17 July and 10–24 July considered the best transplanting window in Pabna and Rajshahi, respectively.

Conclusions: Location specific suitable transplanting windows were selected considering minimum ID at reproductive phase and the maximum grain yield. Delay in transplanting demanded more irrigation and reduced grain yield. Whereas, early transplanting utilized maximum rainfall, reduced ID in reproductive stage and ensured desired grain yield.

Keywords: Effective rainfall, Crop water requirement, Irrigation demand, T. Aman rice, Transplanting window

Background

Rice is extremely vulnerable to water stress at its reproductive phase and water demand at flowering stage highly impact rice yield (Yang et al. 2019). For T. Aman rice (rainfed rice), water stress at the vegetative phase caused about 20–25% yield loss and that of at the reproductive phase caused as high as 28–50% yield loss (Sattar 1993; Yang et al. 2019).

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According to Bangladesh Bureau of Statistics (BBS), T. Aman rice is a major crop of Bangladesh agriculture as it contributes around 39% of the total rice production (BBS 2019). Though Bangladesh agriculture has achieved plenty of technological advancement in developing the modern rice varieties and improved irrigation systems, rainfall is still the key climatic factor which determines the irrigation water need as well as the grain yield production (Sattar and Parvin 2009a). In the coming future, long dry spell, severe water stress, and erratic rainfall distribution due to climate change will rise agricultural water demand, mainly the irrigation demand, for rainfed rice cultivation (Fischer et al. 2007). Insufficient rainfall results less water storage in soil profile that exhibit more volatility in yield performance (Rosenzweig et al. 2002). Water stress from soil water unavailability due to absence of rainfall, causes agricultural drought under rainfed condition, is one of the prime abiotic stresses that hamper crop harvesting (Biswas et al. 2019; MDMR-CEGIS 2013).

In Bangladesh, average annual rainfall distribution varies from 1500 mm in the west and central zones to more than 3000 mm in the north-east and south-east zones (Roy et al. 2014). The months from April to October, which includes rainfed rice growing period, receive most of the total rainfall (about 90 percent). The irrigation demand for rainfed rice reaches the highest in October–November (Saleh 1991). However, sometimes early abruption of monsoon in September causes terrible water stress for T. Aman rice and rainfall shortage triggers tremendous yield loss (Sattar and Parvin 2009b). Due to rainfall seizing, the fate of T. Aman rice sustainability depends on the mitigation of excess irrigation demand from drought (Roy et al. 2010; Khan 1979; Haq et al. 1985; Saleh 1987). Drought management during this period could significantly increase T. Aman rice production in Bangladesh (Islam 2009; Saleh 1987).

Previous research findings (Islam et al. 2009; Hasan and Rahman 2019; Islam and Biswas 2010; Biswas et. al. 2019; Ibrahim 2001) offered three measures to avoid the risk of drought in rainfed rice cultivation: (a) introducing short duration drought tolerant/drought escaping T. Aman variety in the cropping pattern, (b) adjusting transplanting date to avoid drought at critical growth stages, and (c) lessening the increased irrigation demand due to drought through supplemental irrigation. Despite the options, farmers are reluctant to pick those alternatives all the time. Though supplemental irrigation application is the most appropriate way to mitigate drought at the critical stages, farmers often hesitate to set-up irrigation pumps at that period. As rainfed rice cultivation mostly depends on rainwater, famers usually bring back their pumps after the dry season rice cultivation from the field to a safe storage and keep there until next dry season. Supplemental irrigation includes cost and labor for pump installation, fuel, and irrigation water supply, so it would not be a first choice for many farmers. Drought escaping or tolerant rice variety strictly needs to transplant in a very specific time if farmers want to avoid water stress and irrigation demand before the reproductive stage. However, farmers always not get that opportunity to prepare the land for transplanting in right time due to water and labour shortage. Adjusting the transplanting dates would be a comparatively flexible choice for farmers because it gives relatively longer transplanting window for traditional long duration modern T. Aman verities.

Research studies regarding T. Aman rice transplanting date adjustment in terms of rainfall occurrence and drought mitigation were limited. Moreover, most of the findings of the previous studies were based on model simulation, not the experimentation based. A water balance-based drought model study in Rajshahi region revealed that T. Aman rice transplanted between 5 and 25 July suffered medium water stress from agricultural drought with acceptable yield loss and yield reduction risk was totally unavoidable when rice was transplanted after 25 July (Islam et al. 2009, Islam and Biswas 2010). However, the model quantified drought amount at different phases considering only the water deficit in root zone and it did not take into account other crop, soil or climatic parameters. Hasan and Rahman (2019) conducted a simulated study to figure out climate change impacts on T. Aman rice yield using PRECIS and DSSAT models for 12 representative locations across Bangladesh. They recommended transplanting on 15 July was the optimum transplanting date for most of the locations, however they did not find a specific transplanting window. Han et. al. (2019) identified a transplanting window between late-July and mid-August in their DSSAT model-based study, but their recommendation was not location specific rather than a generalized suggestion for whole the country.

In our study, we hypothesized that the suitable transplanting window would spatially varies due to location specific rainfall pattern and farmers would be benefited from the best possible yield if they had location specific transplanting date information. In this circumstance, we could simply develop relationship between crop irrigation demand at different growth phase and grain yield of the T. Aman rice. The present study, therefore, aimed to determine the opportunity to utilize maximum rainfall during T. Aman season in a moderately drought-prone Kushtia region by figuring out suitable transplanting window of a long duration rice variety (BR11), assuming that yield would not be reduced through water stress risk avoidance at different growth phases. The experimental findings further applied to predict adjusted preferable transplanting dates in two adjacent locations, Pabna and Rajshahi, based on rainfall distribution analysis.

Materials and methods

Study location

The field experiment was conducted at Irrigation Extension Training Center (IETC), Kushtia, Bangladesh during T. Aman, 2013–2015. The study area (Kushtia) locates in 23.92°N to 89.2°E. The average maximum temperature is 37.8 °C and the average minimum is 9.2 °C in Kushtia. The mean annual rainfall of Kushtia is 1478 mm (Hossain et al. 2016). About 68% areas of Kushtia district is covered by irrigation. In this study, Kushtia is considered as experimental site.

The study involved two implementing sites, Panba and Rajshahi district near to Kushtia. Pabna locates in between 23.8°N and 24.35°N and in between 89°E and 89.73°E. The average high temperature is 31.2 °C and the average low is 20.8 °C and annual rainfall averages 1603 mm. Rajshahi locates in between 24.12°N and 24.72°N and in between 88.28°E and 88.97°E. About 50% areas are covered by irrigation in Rajshahi. The average high temperature is 32.2 °C, average low temperature is 20.6 °C and annual average rainfall is 1542 mm. The location map of experimental and implementing sites is presented in Fig. 1.

Physiographically, all three locations belong to AEZ-11 (High Ganges river flood plain) and typically rice growing medium high land. Soil texture varies from clay loam to sandy loam. The pH of the soil ranges from 7.0 to 8.5. The soils are moderately fertile and are characterized by calcium carbonate content and are well supplied with phosphate and potassium.

Experimental design and treatments

Bangladesh Rice Research Institute (BRRI) developed long duration cultivar BR11 was used in this study. The standard growth duration of BR11 is 145 days with national average yield of 5.5 t ha^{-1} (BRRI 2019). The vegetative, reproductive, and ripening phases of BR11 were considered from transplanting to panicle initiation (PI), PI to flowering, and flowering to maturity, respectively (Yoshida et al. 1981). The field experiment in Kushtia was carried out following randomize complete block design (RCBD) with three replications (FAO 2005). Individual plot size was 42 m^2 maintaining 1 m gap between two replications. Thirty-days-old rice seedlings were transplanted with BRRI recommended fertilizer doses @164-60–104-67 kg ha^{-1} of Urea-TSP-MoP-Gypsum, respectively. The whole amount of P (Phosphorous), K (Potassium), S (Sulpher) and Zn (Zinc) fertilizer were applied as basal dose during land preparation. Urea was top-dressed in three equal splits at 15 days after transplanting (DAT), 30 DAT and 40 DAT. The experiment involved six transplanting dates as treatment: 10 July, 17 July, 24 July, 31 July, 07 August, and 14 August. Each treatment received the same intercultural management practices although no supplemental irrigation was applied to mitigate agricultural drought.

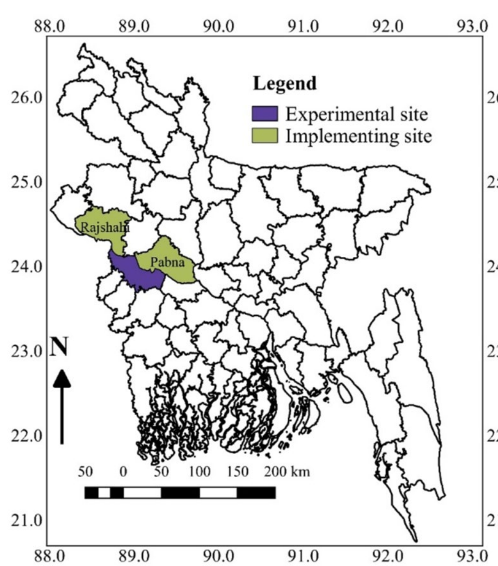

Fig. 1 Locations of the study areas showing the experimental site (Kushtia) and the implementing sites (Pabna and Rajshahi)

Data collection and processing

For this study, daily rainfall during the growing period was collected from a rain gauge (All-weather rain gauge, BAP Equipment Ltd.) installed near to the experimental field. We also collected daily weather data of maximum and minimum air temperature, relative humidity, wind speed and bright sunshine hours from Bangladesh Meteorological Department (BMD) weather stations at Chuadanga (for Kushtia), Ishwardi (for Pabna) and Rajshahi. BMD is a government organization authorized to collect all kind of weather data using standard protocol and instruments. During the data processing, we identified the missing data and imputed by simple arithmetic average method (Gomez and Gomez 1984) using Eq. (1).

$$P_x = \frac{1}{m}(P1 + P2 + P3 + \ldots + Pm), \tag{1}$$

where, P_x is the estimated value, m is number of observation, P1, P2, P3... Pm are observed values. The abnormal data were identified using outlier detection technique and corrected it using the same method in Eq. (1).

In the experiment, rice yield and moisture content were assessed taking samples from 10 square meter area of each plot. Finally, yield was adjusted to 14% moisture content using Eq. (2).

$$Yield_{adjusted} = \frac{(100 - moisture\ content)}{(100 - 14)} \times Yield_{10\ m^2}. \tag{2}$$

Estimation of crop water requirement, effective rainfall, and irrigation demand

Crop water requirement is the amount of water plant uptake through its rooting system essential for plant growth and development (Michael 1974). Food and agriculture organization (FAO) defined crop water requirement (CWR) as "the depth of water needed to meet the water loss through evapotranspiration (ET_{crop}) of a disease-free crop, growing in large fields under non-restricting soil conditions including soil water and fertility and achieving full production potential under the given growing environment" (Doorenbos and Pruitt 1992). Basically, CWR equals crop evapotranspiration under standard conditions and it is expressed as:

$$\mathrm{CWR} = \sum (\mathrm{ET_o} \times \mathrm{k_c}), \tag{3}$$

where CWR is crop water requirements in mm, ET_0 is reference crop evapotranspiration (mm) and k_c is crop coefficient.

This study used FAO developed CROPWAT 8.0 model which utilizes Penman–Monteith method (Allen et al. 1998) to calculate potential evapotranspiration from the collected daily weather data. The Penman–Monteith method is:

$$ET_0 = \frac{0.0408\ \Delta\ (R_n\ - G) + \gamma \frac{900}{T+273} U_2 (e_s - e_a)}{\Delta + \gamma (1 + 0.34\ u_2)}, \tag{4}$$

where, ET_0 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}); $(e_s - e_a)$ 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.

Irrigation demand (ID) refers to the amount of water that needs to be supplied. ID was calculated according to FAO (2005) as:

$$ID = \sum \left(ET_c - P_{effective}\right), \tag{5}$$

where ET_c is crop evapotranspiration in mm, and $P_{effective}$ is effective rainfall in mm.

Effective rainfall is the portion of total rainfall effective for plant growth and development (Hossain et al. 2017). FAO has defined effective rainfall as the part of total annual or seasonal rainfall which is directly or indirectly useful for crop production at the site where it falls, but without pumping (Dastane 1974). The effective rainfall was calculated using USDA soil conservation service method (Geleta 2019; USDA 1997) and is given below:

$$P_{effective} = P * \frac{(125 - 0.2\ P)}{125} \quad \text{For } P < 250 \text{ mm}, \tag{6}$$

$$P_{effective} = 125 + 0.1\ P \quad \text{For } P > 250 \text{ mm}, \tag{7}$$

where, $P_{effective}$ is effective rainfall (mm) and P is monthly rainfall (mm).

In this study, we calculated seasonal and phase-wise crop water requirement, effective rainfall and irrigation demand for three study locations (Kushtia, Pabna and Rajshahi) under varying transplanting dates during T. Aman, 2013 to T. Aman, 2015.

Relationship between yield and irrigation demand

We calculated irrigation demand (ID) for different growing phase using the equation (v) for Kushtia. Relationship was developed between phase-wise ID and grain yield using regression analysis. From the relationships, we figured out the strongest interaction considering regression coefficient value (R^2) in which phase-wise ID affected grain yield the most. The relationship was then validated with observed (BRRI 2017; Rahman and Islam 2019) and predicted grain yield data of BR11 in Kushtia during T. Aman, 2016. We analyzed the relationship performance with prediction error (P_e), coefficient of determination (R^2), normalized root mean square error (nRMSE), degree of agreement (d). The equations are given below:

$$nRMSE\ = \frac{1}{\bar{O}} \sqrt{\frac{\sum_1^n (P_i - O_i)^2}{N}} \times 100. \tag{8}$$

$$P_e = \frac{(P_i -\ O_i)}{O_i} \times 100. \tag{9}$$

$$R^2 = \left[\frac{\sum \left(O_i - \bar{O}\right)\left(P_i - \bar{P}\right)}{\sqrt{\sum \left(O_i - \bar{O}\right)^2 \sum \left(P_i - \bar{P}\right)^2}} \right]^2. \tag{10}$$

$$d = 1 - \frac{\sum_{i=1}^{N} (P_i - O_i)^2}{\sum_{i=1}^{N} \left(\left|P_i - \bar{O}\right| + \left|O_i - \bar{O}\right|\right)^2}. \tag{11}$$

The coefficient of determination (R^2) value closes to 1 indicate a good agreement and value greater than 0.5 considered acceptable (Moriasi et al. 2007). We considered the prediction excellent if nRMSE is smaller than 10%, good between 10 and 20%, fair between 20 and 30% and poor if larger than 30% (Raes et al. 2012). The *d* value of 0 indicate no agreement and 1 indicate a perfect agreement between predicted and observed data (Willmott 1984).

The selected relationship was applied to adjacent locations (Pabna and Rajshahi) for estimating grain yield under varying transplanting dates during T. Aman, 2014–2016.

Selection criterion of suitable transplanting window

A suitable transplanting window for Kushtia was selected based on observed yield performance of the cultivar from the experiment having varying transplanting dates. T. Aman rice transplanted in a specific date which gave equal or higher grain yield than that of national average (5.5 t ha^{-1}) in each year was recommended for suitable establishment window. The same selection criterion was applied in Pabna and Rajshahi to identify the suitable transplanting period from the estimated grain yield.

Results and discussions

Normalize rainfall distribution and crop water requirement

Monthly normal rainfall distribution and potential evapotranspiration of Pabna, Kushtia and Rajshahi regions were determined (Fig. 2). In each location, the highest effective rainfall observed in the month of July, though similar values were observed during June–September. However, in the other months effective rainfall was lower due to less rainfall occurred in this period. This was happened because rainfall distribution in Bangladesh is almost seasonal and uneven. More than 72% of total rainfall occurs during monsoon (June–September) and only 10% in late monsoon (October–November) in the north-west hydrological region of Bangladesh (Hossain et al. 2017). Monthly potential evapotranspiration (ET_0) showed an increasing trend from January and reached its peak in April. This period was the driest period of Bangladesh and effective rainfall was not sufficient to meet the consumptive use (ET_0) of crops. Rainfall was sufficient for the crop water demand only from June to September and irrigation application needed in the other months. Rainfall variation often caused water shortage during the latter part of monsoon to post monsoon season. Asada and Matsumoto (2009) showed an increasing drought effect from increasing rainfall variation in the Brahmaputra river basin.

Crop water requirement, rainfall, and irrigation demand at experimental site

The vegetative phase of all planting dates received sufficient rainfall to meet the crop water requirement (CWR) of BR11 in all the tested year (Table 1). CWR during the reproductive phase exceeded the rainfall in T. Aman, 2014 and 2015 for all transplanting dates except in 2013. Seasonal CWR was found the highest when the rice was transplanted on 10 July and showed decreasing trend on delay transplanting. This could be explained by the decreasing mean daily air temperature and sunshine hours (Hossain et al. 2017). The rainfall shortage was observed in all the years since insufficient rainfall occurred during October–November. T. Aman crop received almost no rainfall in both reproductive and ripening phases when it was transplanted after 31st July. Among the three years field experiments, it was found that ripening phase received comparative higher rainfall in 2013 than 2014 and 2015. Table 2 showed no irrigation demand in vegetative phase in all three years. Effective

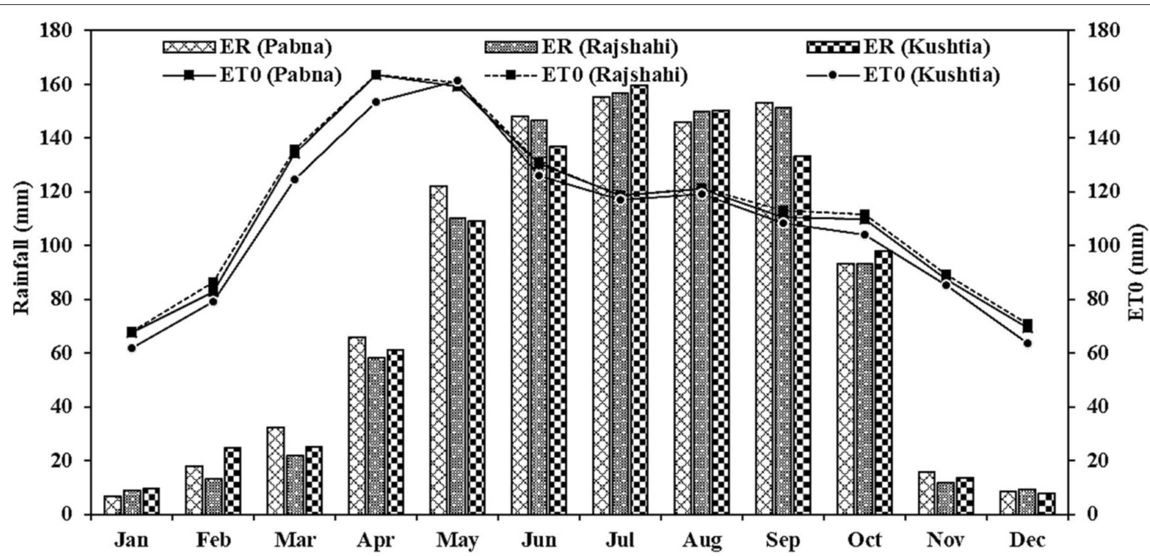

Fig. 2 Monthly distribution of normalize (1981–2017) effective rainfall (ER) and potential evapotranspiration (ET_0) in Kushtia, Pabna and Rajshahi

Table 1 Rainfall and crop water requirement (CWR) amount at different growth phase under varying transplanting dates during T. Aman 2013–2015 in Kushtia

Transplanting date	Vegetative phase		Reproductive phase		Ripening phase		Seasonal	
	Rainfall (mm)	CWR (mm)	Rainfall (mm)	CWR (mm)	Rainfall (mm)	CWR (mm)	Rainfall (mm)	CWR (mm)
2013								
10-Jul	461	301	216	118	95	98	772	517
17-Jul	456	282	202	115	95	100	753	496
24-Jul	442	273	217	111	71	99	730	483
31-Jul	331	264	278	102	10	97	620	463
07-Aug	269	246	288	101	0	98	558	444
14-Aug	387	231	133	99	0	84	521	426
2014								
10-Jul	532	299	86	140	27	108	644	547
17-Jul	492	288	112	135	0	109	605	531
24-Jul	539	288	44	129	0	106	583	522
31-Jul	527	279	27	126	0	102	553	507
07-Aug	449	258	27	122	0	101	476	481
14-Aug	372	230	27	116	0	91	399	437
2015								
10-Jul	716	260	87	126	38	103	841	488
17-Jul	597	253	88	125	24	101	709	478
24-Jul	443	251	77	123	1	95	521	469
31-Jul	399	250	58	121	1	90	458	462
07-Aug	272	238	58	119	1	88	331	445
14-Aug	269	210	58	109	1	75	328	394

rainfall in reproductive phase was sufficient up to 24 July transplanting in 2013. However, delay transplanting showed increasing irrigation demand in reproductive phase in all years. Among the three years, the highest irrigation demand was observed in 2014 since effective rainfall was the lowest in that period. During 2014 and 2015, all the transplanting dates required irrigation water in reproductive and ripening phase.

Irrigation demand (ID) and rice yield at experimental site

BR11 accounted no water demand during the vegetative phase among the three years trial. Hence, no relationship could be established with the grain yield. Figure 3 illustrates the grain yield response to ID in reproductive phase. A significant relationship ($P<0.01$) showed the decreasing trend of grain yield by 0.0138 t ha^{-1} with the increasing ID of 1 mm. This result is identical to Yang et al. (2019) who found that drought stress at flowering significantly affected physiological traits and reduced grain yield of rice. Mild water stress in reproductive phase of rice reduced grain yield by 28% in Tamil Nadu, India in wet season rice 1999–2000 (Babu et al. 2003). Rice is highly susceptible to water stress during the reproductive stage, leading to significant reduction in grain GY (Kamoshita et al. 2008). Grain yield also showed a declining trend with increasing ID at ripening phase (Fig. 4), but the relationship was statistically very weak ($R^2=0.012$).

The predicted grain yield, by developed relationship between irrigation demand at reproductive phase and grain yield, agreed well with observed yield (Table 3). R^2 value (0.71) above 0.5 indicated that relationship did a decent prediction. nRMSE value of 15.1% pointed out good estimation of the relationship. The d value (0.51) represents a perfect agreement between predicted and observed data.

Yield performance of BR11 was analyzed and showed in Fig. 5. Grain yield decreased with the delay transplanting for each year trial. BR11 produced the highest grain yield during 2013 as it showed the less ID for all transplanting dates than 2014 and 2015. Among the transplanting dates, BR11 yielded equal or higher yield than the threshold (5.5 t ha^{-1}) for transplanting 10–24 July. After 24 July transplanting, grain yield reduced significantly. Thus, 10–24 July was found suitable transplanting window for T. Aman rice cultivation in Kushtia.

Table 2 Effective rainfall (ER) and irrigation demand (ID) amount at different growth stages under varying transplanting dates during T. Aman 2013–2015 in Kushtia

Transplanting date	Vegetative phase		Reproductive phase		Ripening phase		Seasonal	
	ER (mm)	ID (mm)	ER (mm)	ID (mm)	ER (mm)	ID (mm)	ER (mm)	ID (mm)
2013								
10-Jul	358	0	118	0	48	50	524	0
17-Jul	350	0	115	0	29	71	494	3
24-Jul	349	0	111	0	0	99	461	22
31-Jul	344	0	84	18	0	97	428	35
07-Aug	335	0	80	21	0	98	415	30
14-Aug	320	0	55	44	0	92	386	22
2014								
10-Jul	435	0	78	62	27	81	539	8
17-Jul	435	0	75	60	0	109	510	22
24-Jul	391	0	77	52	0	106	467	55
31-Jul	356	0	58	67	0	102	414	93
07-Aug	333	0	43	80	0	101	376	105
14-Aug	317	0	27	89	0	91	344	93
2015								
10-Jul	467.3	0	81	45	31	71	580	0
17-Jul	450.32	0	81	43	19	82	551	0
24-Jul	428.9	0	82	41	1	94	512	0
31-Jul	395.32	0	69	52	1	89	465	0
07-Aug	366.41	0	59	60	1	87	426	19
14-Aug	335.5	0	49	59	1	74	386	8

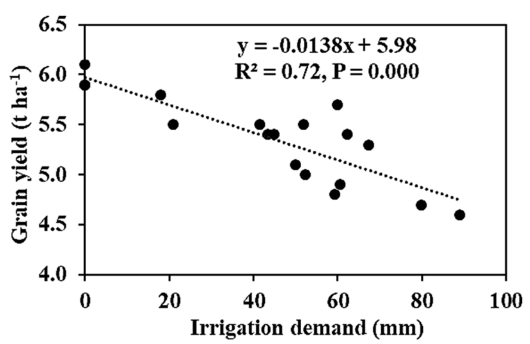

Fig. 3 Relationship between grain yield and irrigation demand of BR11 at reproductive phase in Kushtia during T. Aman, 2013–2015

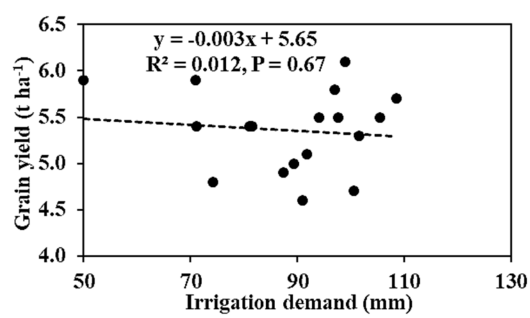

Fig. 4 Relationship between grain yield and irrigation demand of BR11 at ripening phase in Kushtia during T. Aman, 2013–2015

Selection of suitable planting window at implementing sites

Sufficient rainfall occurred during the vegetative phase of T. Aman rice resulting no irrigation demanded in two implementing locations (Panba and Rajshahi). Since water shortage during ripening phase had a little influence on grain yield, irrigation demand was analyzed only for reproductive phase in the implementing sites (Table 4). Effective rainfall had a decreasing trend in both locations, subsequently increased irrigation demand. Rajshahi area experienced comparatively higher irrigation demand than Pabna. Transplanting up to 24 July showed a little irrigation demand (< 10 mm) in Pabna in 2014. All transplanting dates in Rajshahi exhibited irrigation demand in each year.

Predicted yield performance of BR11 in Pabna is presented in Fig. 6. Similar grain yield was estimated in Pabna for transplanting 10 July and 17 July. The minimum observed grain yield was 5.5 t ha^{-1} for transplanting

Table 3 Validation of relationship comparing observed and predicted grain yield with irrigation demand at reproductive phase of BR11 during T. Aman, 2016 in Kushtia

Transplanting date	Observed yield (t ha^{-1})	Predicted yield (t ha^{-1})	Pe (%)	R^2	nRMSE	d
22 July	4.98	5.2411	14.7	0.71	15.1	0.51
1 Aug	4.27	5.1041				
7 Aug	4.3	5.0356				
14 Aug	4.12	4.8164				

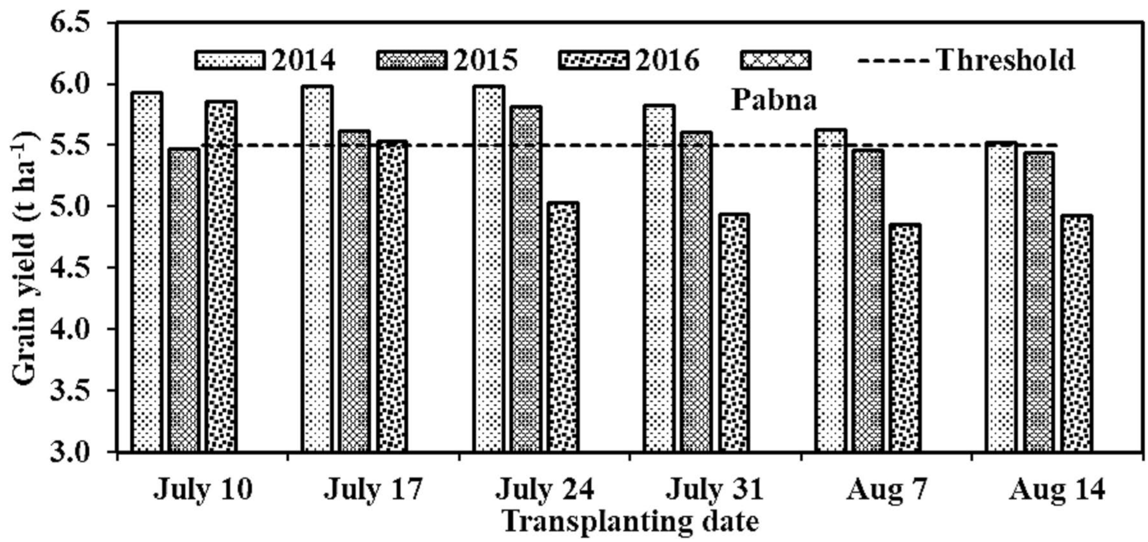

Fig. 5 Yield comparison of BR11 with threshold limit under varying transplanting date in Kushtia

dates up to 17 July, which was same as the threshold yield. Except 2016, grain yield exceeded threshold yield in 24 July, 31 July, and 7 August transplanting for the year 2014 and 2015. Thus, it indicated that transplanting period from 10 to 17 July was suitable and recommended for T. Aman establishment in Pabna.

In Rajshahi, all the transplanting dates demanded irrigation water in reproductive phase, and it showed increasing trend for delay transplanting. Among the three locations (experimental and implementing sites), Rajshahi received the lowest effective rainfall resulting maximum water demand. As a result, no transplanting dates gave yield close to national average yield (5.5 t ha^{-1}). Hence, suitable planting period was selected considering threshold yield 5.0 t ha^{-1} (Fig. 7). The estimated grain yield of BR11 was more than 5.0 t ha^{-1} in each year for the transplanting period 10–24 July. Delay transplanting after 24 July experienced comparatively higher ID and it occurred yield reduction. Thus, 10–24 July was recommended transplanting period in Rajshahi.

Form the above discussion, the selected suitable transplanting window for Kushtia and Rajshahi was 10–24 July while it was 10–17 July for Pabna. Tables 2 and 4 gave an in depth understanding about the reproductive phase ID for three locations. The ID increased sharply for the delay transplanting after 24 July. The late in transplanting often caused considerable grain yield loss. The findings of this study strongly agree with the outcomes of Islam et al. (2009) and Islam and Biswas (2010). They concluded from a model study that 5–25 July was the best preferable transplanting window for T. Aman rice, because crop suffered less drought in reproductive phase, but yield reduction risk was very higher if the transplanting date went beyond 25 July.

Limitations of the study

The study area covered moderate drought prone Kushtia and adjacent Pabna and Rajshahi region. Further, studies in other hydrological environments including severe drought prone and high rainfall area, the results will provide a detail scenarios of suitable transplanting window. We built a relation between grain yield and irrigation demand considering three-year experimental data. The relationship can be fine-tuned with more

Table 4 Crop water requirement (CWR), effective rainfall (ER) and irrigation demand (ID) at reproductive phase in Pabna and Rajshahi under varying transplanting dates during T. Aman, 2014–2016

Year	Date	Pabna			Rajshahi		
		CWR (mm)	ER (mm)	ID (mm)	CWR (mm)	ER (mm)	ID (mm)
2014	10-Jul	117	113	4	129	60	69
	17-Jul	112	114	0	123	65	58
	24-Jul	106	115	0	126	60	66
	31-Jul	108	97	11	124	38	86
	7-Aug	109	83	26	122	5	117
	14-Aug	103	70	33	113	5	108
2015	10-Jul	131	94	36	136	102	34
	17-Jul	127	101	26	132	85	47
	24-Jul	122	110	12	126	53	73
	31-Jul	120	93	27	124	34	90
	7-Aug	118	81	38	122	21	102
	14-Aug	108	68	39	113	7	106
2016	10-Jul	127	118	9	125	102	23
	17-Jul	128	95	33	128	104	24
	24-Jul	130	61	68	131	108	23
	31-Jul	127	52	76	130	95	35
	7-Aug	125	44	81	128	86	42
	14-Aug	113	37	76	119	76	43

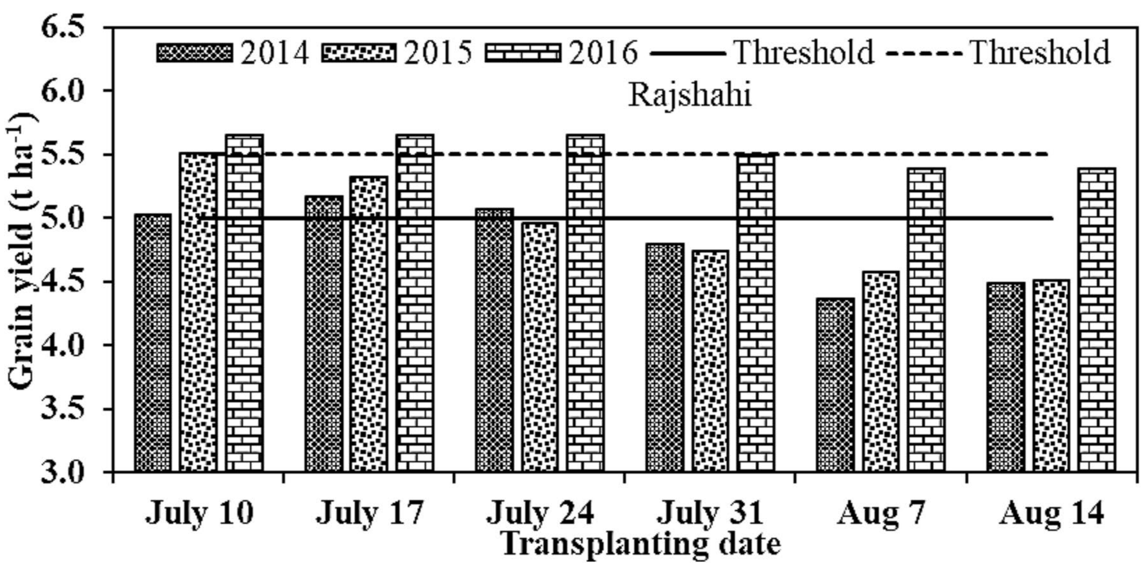

Fig. 6 Yield comparison of BR11 with threshold limit under varying transplanting date in Pabna

trials in different locations and years. BR11 is a drought susceptible cultivar whereas, validation with a tolerant cultivar will give a better understanding about selecting transplanting window. The study considered only rainfall and irrigation demand to T. Aman rice production, however other climatic parameters like temperature, solar radiation, carbon di oxide concentration etc. can be incorporated for future study. A policy level study can be executed to estimate the yield advantage from recommended transplanting window to national rice production.

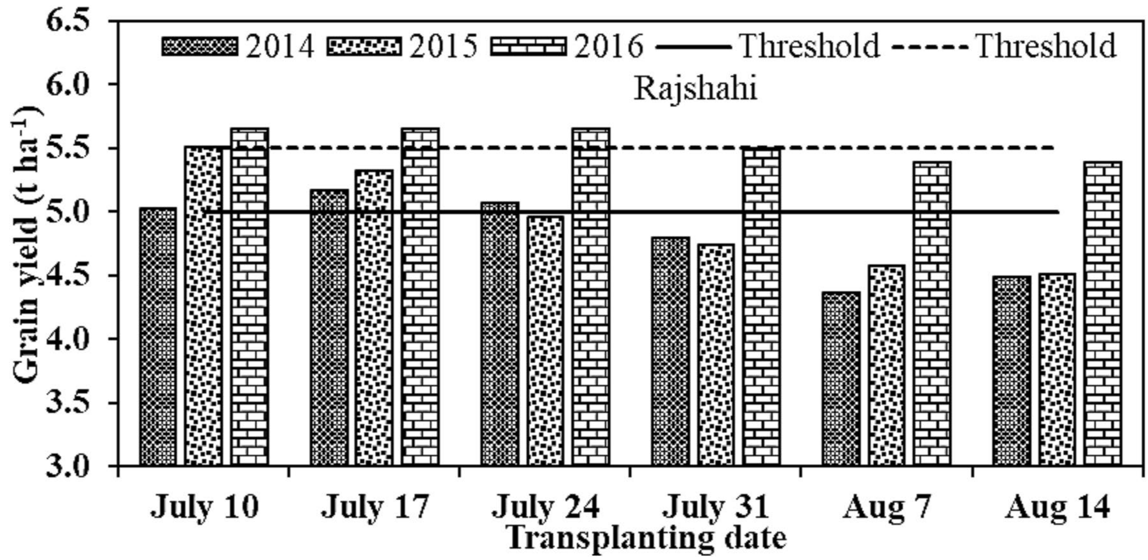

Fig. 7 Yield comparison of BR11 with threshold limit under varying transplanting date in Rajshahi

Conclusions

Uneven rainfall distribution during the rainfed rice (T. Aman) cultivation often caused water stress in the drought prone northwest region of Bangladesh. The ample rainfall in early growing period (vegetative phase) accounted no irrigation in Kushtia, Pabna and Rajshahi. Conversely, varying rainfall after the month of August failed to meet the consumptive use of rainfed rice and caused agricultural drought. Considering maximum utilization of rainfall, the study revealed that 10–24 July transplanting window was appropriate for Kushtia and Rajshahi while 10–17 July window was suitable for Pabna. It could be highlighted from the findings of the study that the desirable grain yield could be achieved if farmers adopt the recommended transplanting windows in respective locations. They also do not need to accommodate short duration drought tolerant/escaping cultivar which usually give less yield than long duration cultivar (BR11) in their cropping pattern. Additionally, they do not require supplemental irrigation from groundwater sources which increases production cost and fuel consumption. Farmers can get maximum benefit from T. Aman rice cultivation in rainfed condition if they adopt the recommended transplanting windows.

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Authors' contributions

MBH: Conceptualization, methodology, software, validation, manuscript preparation. DR: Conceptualization, experimentation, manuscript preparation. MNHM, PLCP, MSY, PKK: Reviewed and edited the final manuscript. All authors read and approved the final manuscript.

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