

Early Transplanting of Rainfed Rice Minimizes Irrigation Demand by Utilizing Rainfall

Md. Belal Hossain (✉ belal.iwm@gmail.com)

Bangladesh Rice Research Institute

Debjit Roy

Bangladesh Rice Research Institute

Mir Nurul Hasan Mahmud

Bangladesh Rice Research Institute

Priya Lal Chandra Paul

Bangladesh Rice Research Institute

Mst. Shetara Yesmin

Bangladesh Rice Research Institute

Palash Kumar Kundu

Bangladesh Rice Research Institute

Research Article

Keywords: Effective rainfall, crop water requirement, irrigation demand, T. Aman rice, transplanting window

Posted Date: April 19th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-407986/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Version of Record: A version of this preprint was published at Environmental Systems Research on July 7th, 2021. See the published version at <https://doi.org/10.1186/s40068-021-00239-z>.

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 utilized maximum rainfall for long duration (145 days) rice cultivar. Firstly, three years field experiment conducted in Kushtia, Bangladesh in T. Aman season from 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 at 7 days interval starting from 10 July up 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. A suitable transplanting window was selected considering minimum ID at reproductive phase and the maximum grain yield.

Results

T. Aman rice received enormous rainfall and accounted no irrigation at vegetative phase in all three tested years in all locations. The early transplanting received more rainfall in reproductive phase than late planting practice. 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 ID at reproductive phase to 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. Applying ID vs yield relationship, 10-17 July and 10-24 July considered the best transplanting window in Pabna and Rajshahi, respectively.

Conclusions

Delay in transplanting demanded more irrigation and reduced yield. Consequently, early transplanting utilized maximum rainfall, reduced ID in reproductive stage and ensured desired grain yield.

Background

Rice is extremely vulnerable to water stress at its reproductive phase (Yang et al., 2019). Specially, water demand at flowering stage highly impact rice yield and other physiological features. The grain yield could significantly reduce if rice reproductive phase water need is not satisfied. The loss in yield of rice mostly depends on the extent and severity of water stress. Sattar (1993) stated that, for transplanted Aman rice (i.e. rainfed rice or, T. Aman rice), water stress at the vegetative phase caused about 25% yield loss and that of at the reproductive phase caused as high as 50% yield loss. Yang et al. (2019) also reported grain yield loss of 20% and 28% due to water stress at the vegetative and reproductive phase, respectively.

Rainfed Aman rice contributes 39 percent of the total rice production of Bangladesh (BBS, 2019). Hence, it is considered as a major crop in Bangladesh agriculture. Though Bangladesh agriculture achieved plenty of technological advancement in developing modern rice varieties and improved irrigation systems, T. Aman production still depends on weather and climatic conditions. In coming future, lengthy dry spell, and severe water stress due to climate change will rise agricultural water demand, mainly the irrigation demand, for rainfed rice (Fischer et al., 2007). Consequently, the changed climatic situation results erratic rainfall distribution and changes the occurrence of adequate rainfall at the exact period of rice growth phase, thus causes water stress. The rainfed agriculture, i.e., rainfed rice will experience the instant impact of climate change for uneven rainfall, because insufficient rainfall amount results moisture stress in soil profile that exhibit more volatility in yield performance (Rosenzweig et al., 2002). The fact for T. Aman rice cultivation is that rainfall is still the key climatic factor which determines the irrigation water need as well as the grain yield production (Sattar et al. 2009a).

When the enough rainfall is lacking, it leads to moisture depletion in soil profile and creates water deficit in crop root zone. If the water shortage in vadose zone hits the limit, the soil profile cannot supply sufficient water that requires for maintaining natural crop growth and development. This condition implies water stress in crop-soil-water system, generates irrigation water demand to sustain the crop. This condition can be defined as agricultural drought (Biswas et al., 2019; MDMR-CEGIS, 2013). In Bangladesh, water stress from soil water unavailability due to absence of rainfall, which causes agricultural drought under rainfed condition, is one of the prime abiotic stresses that hamper crop harvesting (Biswas, 2011). Bangladesh average annual rainfall distribution varies from 1500 mm in west and central zones to more than 3000 mm in north-east and south-east zones (Roy et al., 2014). The months from April to October, which includes rainfed rice growing period, receive the most of total annual rainfall (about 90 percent). However, sometimes early abruption of monsoon in September causes terrible water stress for T. Aman rice. Around the months of September and October, usually the rainfed rice is in between reproductive and ripening phases (flowering stage to grain filling stage) and rainfall shortage triggers tremendous yield loss (Sattar et al., 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). The irrigation demand for rainfed rice reaches the highest in October-November (Saleh, 1991). The erratic distribution of rainfall is the reason behind the huge water shortage in those months, though the seasonal rainfall happening during the crop growth span generally exceeds total crop water requirement of T. Aman rice (Khan, 1979; Haq et al., 1985; Saleh, 1987). Drought management during this period could significantly increase T. Aman rice production in Bangladesh (Islam, 2007; Saleh, 1987; BRRI, 1991).

Different research findings 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 (Islam et al., 2009; Hasan et al., 2014; Islam and Biswas, 2010; Biswas et. al., 2019; Ibrahim, 2001). Despite the options, farmers are not interested to pick those alternatives all the time. Though supplemental irrigation application is the most appropriate way to mitigate drought at critical stages, farmers often hesitate to set up irrigation pumps at

that period. As rainfed rice cultivation mostly depends on rainwater, farmers 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 varieties. A model study revealed that T. Aman rice transplanted between 5-25 July suffered medium water stress from agricultural drought, when yield reduction risk was totally unavoidable if the rice was transplanted after 25 July (Islam et al., 2009, Islam and Biswas, 2010). Anyway, the suitable transplanting window may spatially vary due to location specific rainfall pattern.

The present study aimed to experiment the opportunity to utilize maximum rainfall portion during the T. Aman growth spell in a moderately drought-prone site, Kushtia, by figuring out suitable transplanting window of a long duration rice variety (BR 11), assuming that yield would not be reduced through water stress risk avoidance at different growth phases. The experimental findings later 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 to 2015. Kushtia locates in 23.92° N to 89.2° E. The average high temperature is 37.8°C and the average low is 9.2°C in Kushtia. The mean annual rainfall of Kushtia is 1478 mm (Hossain et al., 2016). In Kushtia, about 68% areas are covered by irrigation. In this study, Kushtia is considered as experimental site.

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 Figure 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, 1981). The field experiment carried out at Irrigation Extension Training Center (IETC), Kushtia, Bangladesh following randomize complete block design (RCBD) with three replications. Individual plot size was 42 m² maintaining 1 m gap between two replications. Thirty-days-old rice seedlings were transplanted with BRRI recommended fertilizer doses. The whole amount of P (Phosphorous), K (Potassium), S (Sulphur) 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. Rice yield was assessed taking samples from 10 square meter area of each plot.

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:

$$CWR = \sum(ET_0 \times k_c) \quad (i)$$

Where CWR is crop water requirements in mm, ET₀ is reference crop evapotranspiration (mm) and k_c is crop coefficient. Daily rainfall during the growing period was collected from a rain gauge installed near to the experimental field. The daily weather data of maximum and minimum air temperature, relative humidity, wind speed and bright sunshine hours were collected from Bangladesh Meteorological Department (BMD) weather stations at Chuadanga (for Kushtia), Iswardi (for Pabna) and Rajshahi. This study used FAO developed CROPWAT 8.0 model which utilizes Penman-Monteith method (Allen, 1998) to calculate potential evapotranspiration from the collected daily weather data. The Penman-Monteith method is:

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

Where, ET_0 is reference crop evapotranspiration (mm d^{-1}); R_n is net radiation at the crop surface ($\text{MJ m}^{-2}\text{d}^{-1}$); G is soil heat flux ($\text{MJ m}^{-2}\text{d}^{-1}$); T is average air temperature ($^{\circ}\text{C}$); 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 ($\text{kPa}^{\circ}\text{C}^{-1}$); γ is psychrometric constant ($\text{kPa }^{\circ}\text{C}^{-1}$) 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:

$$ID = \sum(ET_c - P_{\text{effective}}) \quad (\text{iii})$$

Where ET_c is crop evapotranspiration in mm, and $P_{\text{effective}}$ 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 CD, 2019; USDA, 1997) and is given below:

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

$$P_{\text{effective}} = 125 + 0.1 P \quad \text{For } P > 250 \text{ mm} \quad (\text{iv})$$

Where, $P_{\text{effective}}$ is effective rainfall (mm) and P is monthly rainfall (mm)

Selection criteria of suitable transplanting window

A suitable transplanting window was selected based on yield performance of the cultivar established in varying transplanting dates. The transplanting dates gave equal or higher grain yield than that of national average (5.5 t ha^{-1}) in each year trial was recommended for T. Aman establishment.

Results And Discussion

Normalize rainfall distribution and crop water requirement

Monthly normal rainfall distribution and potential evapotranspiration of Pabna, Kushtia and Rajshahi region were determined and presented in Figure 2. In each location, the highest effective rainfall observed in the month of July, though similar values were observed during June to September. However, in the other months effective rainfall was low due to less rainfall occurred in this period. This was happened because rainfall distribution in Bangladesh is almost seasonal and more than 72% of total rainfall occurs during monsoon (June to September) and only 10% in late monsoon (October-November) in the northwest hydrological region of Bangladesh (Hossain et al, 2017). Monthly potential evapotranspiration

(ET₀) showed a rising 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 (ET₀) 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 (2006) 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 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 to 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 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 demanded irrigation water in reproductive and ripening phase.

Table 1. Phase wise rainfall distribution and crop water requirement (CWR) for different transplanting dates during T. Aman 2013 to 2015 at Kushtia.

Transplanting date	Vegetative phase		Reproductive phase		Ripening phase		Seasonal	
	Rainfall	CWR	Rainfall	CWR	Rainfall	CWR	Rainfall	CWR
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

Table 2. Effective rainfall (ER) in mm and irrigation demand (ID) in mm at different growth stages for different transplanting dates during T. Aman 2013 to 2015 at Kushtia.

Transplanting date	Vegetative phase		Reproductive phase		Ripening phase		Seasonal	
	ER	ID	ER	ID	ER	ID	ER	ID
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

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 (Figure 4), but the relationship was statistically very weak ($R^2 = 0.012$).

Yield performance of BR11 was analyzed and showed in Figure 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.

Selection of suitable planting window at implementing sites

Sufficient rainfall occurred during the vegetative phase of T. Aman rice resulting no irrigation demand in two implementing locations, Panba and Rajshahi. Since water shortage during ripening phase has a little influence on grain yield, irrigation demand was analyzed only for reproductive phase in the implementing sites and presented in Table 3. Effective rainfall has a decreasing trend in both locations, subsequently increased irrigation demand. Rajshahi experienced comparatively higher irrigation demand than Pabna. T. Aman rice showed a little irrigation demand ($<10 \text{ mm}$) up to 24 July transplanting in Pabna during 2014. All transplanting dates in Rajshahi exhibited irrigation demand in each year.

Predicted yield performance of BR11 in Pabna is presented in Figure 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 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 suitable transplanting period from 10 July to 17 July, 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} (Figure 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.

Table 3. Crop water requirement (CWR), effective rainfall (ER) and irrigation demand (ID) at reproductive phase in Pabna and Rajshahi during T. Aman, 2014 to 2016.

Year	Date	Pabna			Rajshahi		
		CWR	ER	ID	CWR	ER	ID
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

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. Table 2 and Table 3 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.

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, 10-24 July transplanting window was recommended for Kushtia and Rajshahi while 10-17 July window was suitable for Pabna. If farmers adopt the recommended transplanting windows in respective locations, they do not need to accommodate short duration drought tolerant/escaping cultivar in their cropping pattern as well as do not require to apply supplemental irrigation. Also transplanting within the suitable period ensure desirable rice yield.

Declarations

Acknowledgement

The authors would like to express heartfelt gratitude to Agricultural Land and Water Resources Management (ALAWRM) Research Group, Irrigation and Water Management Division, Bangladesh Rice Research Institute for their kind support and help throughout the study.

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

Funding

No funding

Availability of data and materials

Not applicable.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declared that there is no conflict of interest

Author details

References

- Allen RG, Pereira LS, Raes D, Smith M (1998) Crop evapotranspiration – Guidelines for computing crop water requirements- FAO Irrigation and drainage paper 56. Food and Agriculture Organizations of the United Nations.
- Asada H, Matsumoto J (2009) Effects of rainfall variation on rice production in the Ganges-Brahmaputra Basin. *Climate Research* 38: 249–260.
- Babu RC, Nguyen BD, Chamarek V et al (2003) Genetic analysis of drought resistance in rice by molecular markers: association between secondary traits and field performance. *Crop Science* 43(4):1457-1469.
- BBS (Bangladesh Bureau of Statistics). (2006) Yearbook of agricultural statistics of Bangladesh, Planning Division, Ministry of Planning, Government of the People's Republic of Bangladesh, Dhaka.
- Biswas JK, Kabir S, Rahman S, Nahar K, Hasanuzzaman M. (2019) Managing abiotic stresses with rice agriculture to achieve sustainable food security: Bangladesh perspective In.: Hasanuzzaman M et al (ed) *Advances in rice research for abiotic stress tolerance*, Woodhead Publishing, Elsevier Inc., Duxford, pp 23-46. <https://doi.org/10.1016/B978-0-12-814332-2.00002-2>
- BRRI (Bangladesh Rice Research Institute). (1991) Internal review report. Irrigation and Water Management Division, Gazipur, pp 149-155.
- BRRI. (2015) Annual report 2013-2014, Bangladesh Rice Research Institute, Gazipur 1701, Bangladesh, pp 320.
- BRRI. (2019) Modern rice cultivation, Bangladesh Rice Research Institute, Gazipur.
- Dastane NG. (1974) A practical manual for water use research in agriculture. Navabharat Prakashan, Poona, pp 120.
- Doorenbos J, Pruitt WO. (1992) Crop water requirements. FAO irrigation and drainage paper 21. Food and Agriculture Organizations of the United Nations, pp. 1-144.
- Fischer G, Tubiello FN, Van Velthuisen H, Wilberg DA (2007) Climate change impacts on irrigation water requirements: effects of mitigation, 1990–2080. *Technological Forecasting and Social Change*. 74 (7):1083-1107.
- Geleta CD. (2019). Effect of first watering month on water requirement of sugarcane using CROPWAT Model in Finchaa Valley, Ethiopia. *International Journal of Water Resources and Environmental*

Engineering 11(1):14-23.

Haq K.A, Islam J, Sattar M.A. (1985) Low irrigation strategies for rice production. Proc. of the Seminar on Low Water Demanding Crops, BARC, Dhaka.

Hossain M.B, Roy D, Paul PLC, Islam MT (2016) Water productivity improvement using water saving technologies in Boro rice cultivation. Bangladesh Rice J. 20(1): 17-22.

Hossain MB, Yesmin S, Maniruzzaman M, Biswas JC (2017) Irrigation scheduling of Rice (*Oryza sativa* L.) using CROPWAT model in the western region of Bangladesh. The Agriculturists 15(1): 19-27.

Ibrahim A. (2001) Application of agroecological zones database in drought management and water availability assessment. Environment and GIS support project for water sector planning, Dhaka, Bangladesh. pp 7-11.

Islam MT, Saleh AFM, Bhuiyan SI. (1998) Agrohydrologic and economic analysis of on-farm reservoirs for drought alleviation in rainfed ricelands of northwest Bangladesh. The Japanese society of irrigation, drainage and reclamation engineering. Rural and environmental engineering. No.35, pp 15-26.

Islam MT, Khan LR, Hassanuzzaman KM. (2009) Integrated approach for mitigating drought in transplanted aman rice in northwest region of Bangladesh. Bangladesh Rice Journal 14(1&2):169-173.

Islam MT, Biswas JK (2010) Natural hazard management in rice production. J. Agric. Engin. 38:63-69.

Kamoshita A, Babu RC, Bhupathi NM, Fukai S. (2008) Phenotypic and genotypic analysis of drought-resistance traits for development of rice cultivars adapted to rainfed environments. Field Crops Res. 109:1–23. <https://doi.org/10.1016/j.fcr.2008.06.010>

Khan HR. (1979) Determination of transplanting date and supplementary irrigation requirement for HYV monsoon rice using rainfall. Bangladesh Journal of Water Resource Research 1(1): 76-85.

MDMR-CEGIS (Ministry of Disaster Management and Relief-Center for Environmental and Geographic Information Services). (2013) Vulnerability to climate induced drought: scenario & impact. Center for Environmental and Geographic Information Services. Comprehensive Disaster Management Programme (CDMP II), Ministry of Disaster Management and Relief. pp 134.

Rosenzweig CE, Tubiello F, Goldberg R, Mills E, Bloomfield J. (2002) Increased crop damage in the U.S. from excess precipitation under climate change. Global Environment Change, A (12):197-202.

Roy D, Ahmmed MU, Mahmud NH. (2014) Water management technologies for sustainable rice cultivation under changing climate. J. Agric. Engin 41/AE (1):3-52.

Roy D, Islam MT, Nath BC. (2010) Impact of supplemental irrigation applied at different growth stages of transplanted aman rice (*Oryza sativa*). The Agriculturists 8(1):109-114.

Saleh AFM. (1987) The effect of supplementary irrigation on rice yield in Bangladesh. *International Rice Research Newsletter* 2(1):25-26.

Saleh AFM. (1991) Supplementary irrigation in Bangladesh: Requirements, benefits, and prospects. *Proc. of the Special Technical Session Proceedings, International Commission on Irrigation and Drainage, China 1-A*: 96-105.

Sattar MA. (1993) Water management and technology adoption for direct seeded rice in an irrigation system. Dissertation, Central Luzon State University, Philippines.

Sattar MA, Parvin MI. (2009a) Sustainable T. Aman rice production in north-west region of Bangladesh for food security under climate change situation. *Proc. of International Conference on Climate Change Impacts and Adoption Strategies for Bangladesh, BUET, Dhaka, Bangladesh*, pp 289.

Sattar MA., Parvin MI. (2009b) Assessment of vulnerability of drought and its remedial measures for sustainable T. Aman rice production in the selected locations of Bangladesh. *Proc. of 2nd International Conference on Water and Flood Management (ICWFM 2009), Dhaka, Bangladesh*, pp 509.

USDA (United States Department of Agriculture). (1997) Natural resources conservation national engineering handbook, irrigation guide, Natural Resource Conservation Service, Washington DC, pp 754.

Yang X, Wang B, Chen L, Li P, Cao C. (2019) The different influences of drought stress at the flowering stage on rice physiological traits, grain yield, and quality. *Scientific Reports*. 9:3742.
<https://doi.org/10.1038/s41598-019-40161-0>

Yoshida S, Satake T, Mackill DS. (1981) High-temperature stress in rice, *IRRI Research Paper Series*, Vol. 67.

Figures

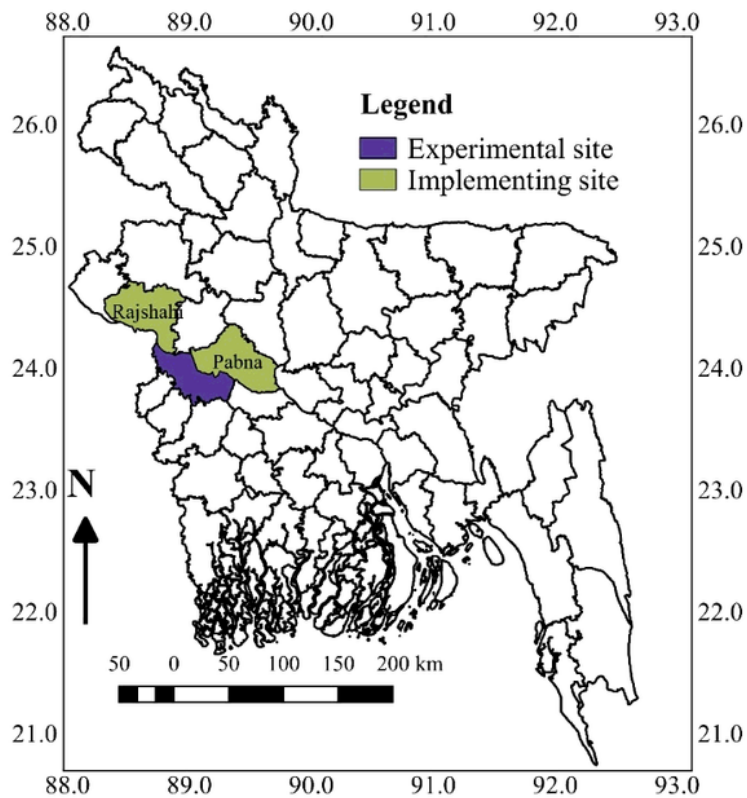


Figure 1

Study locations showing experimental site (Kushtia) and implementing sites (Pabna and Rajshahi) Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

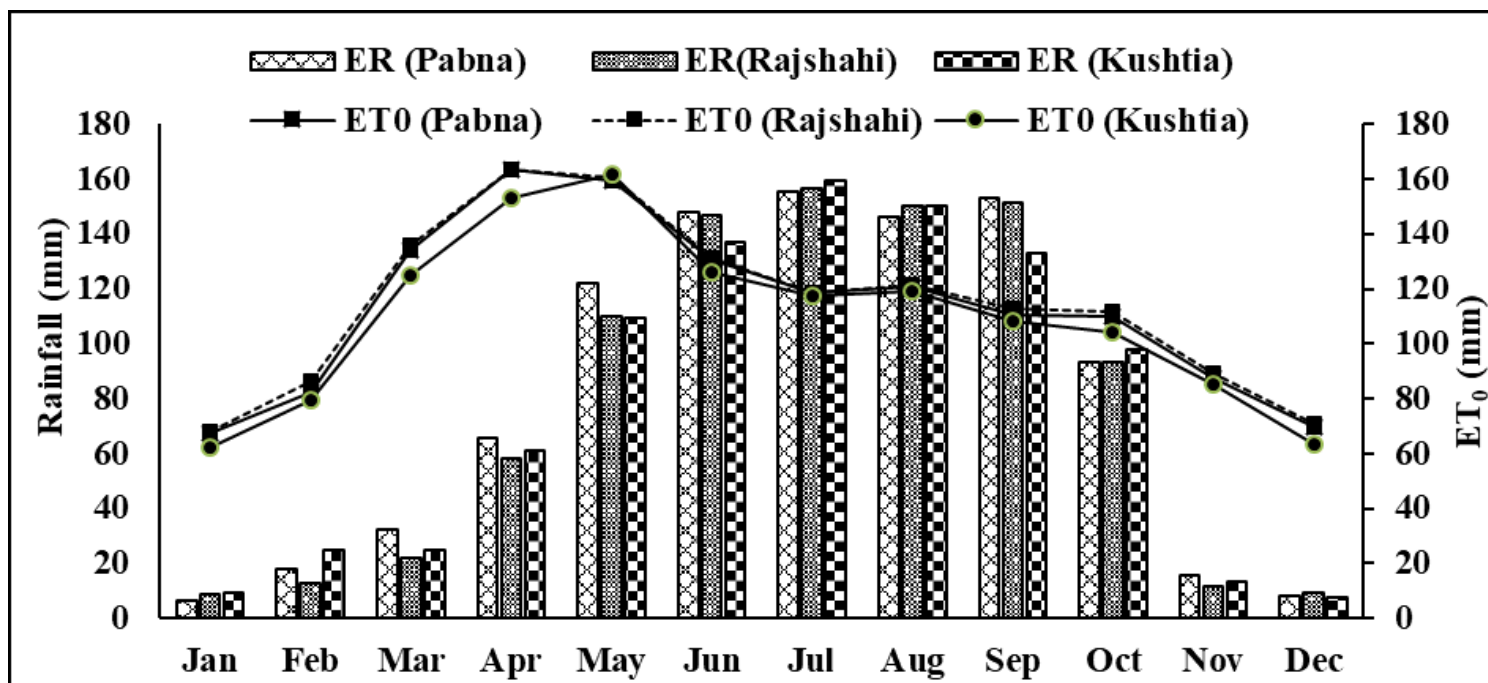


Figure 2

Monthly distribution of normalized (1981-2017) effective rainfall (ER) and potential evapotranspiration (ET₀) in Kushtia, Pabna and Rajshahi areas.

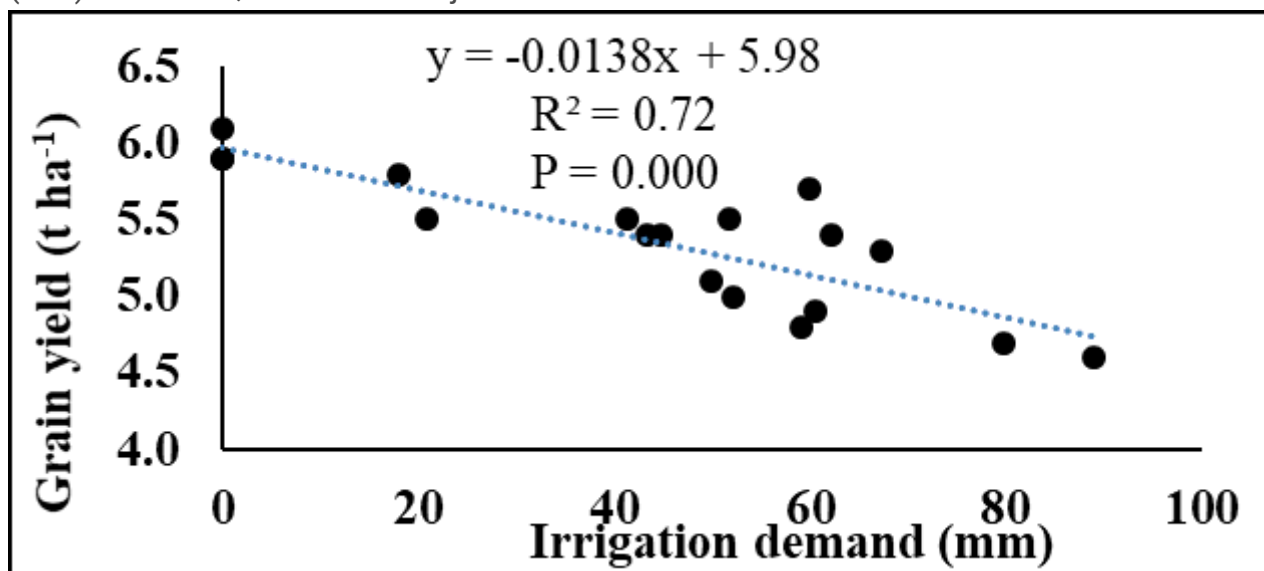


Figure 3

Grain yield of BR11 in relation to irrigation demand at reproductive phase in Kushtia.

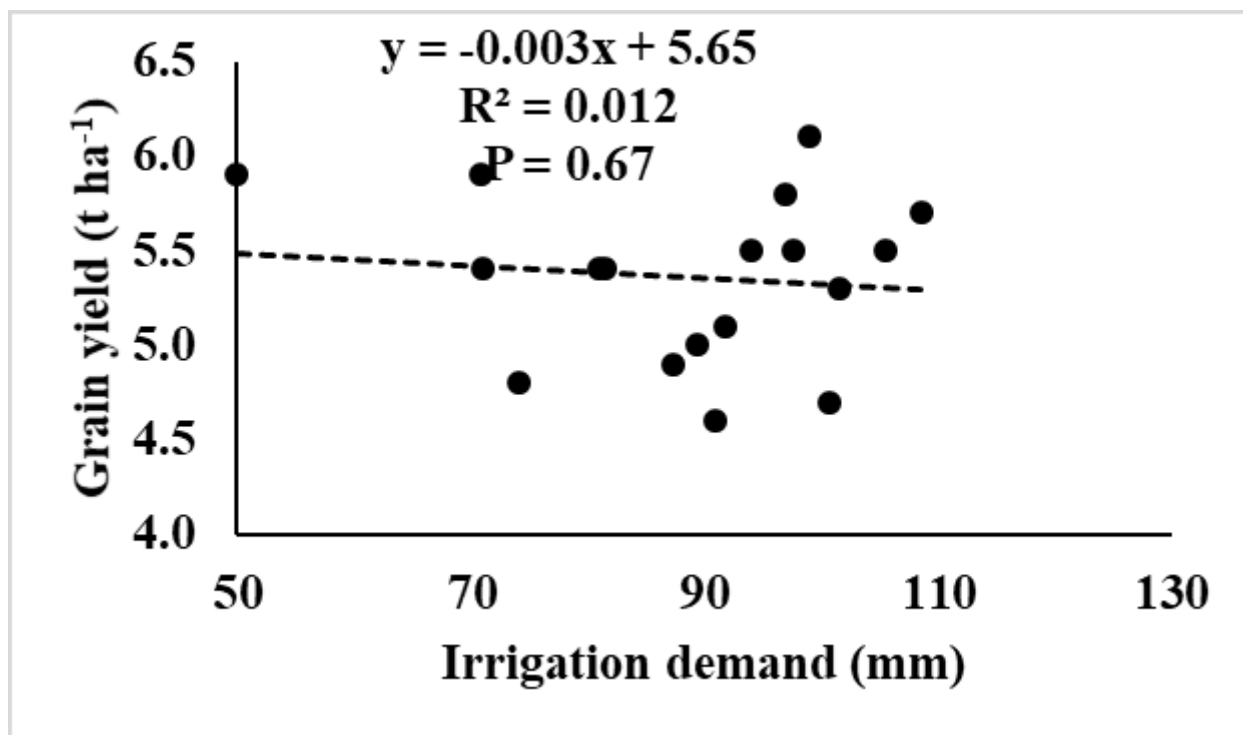


Figure 4

Grain yield of BR11 in relation to irrigation demand at ripening phase in Kushtia.

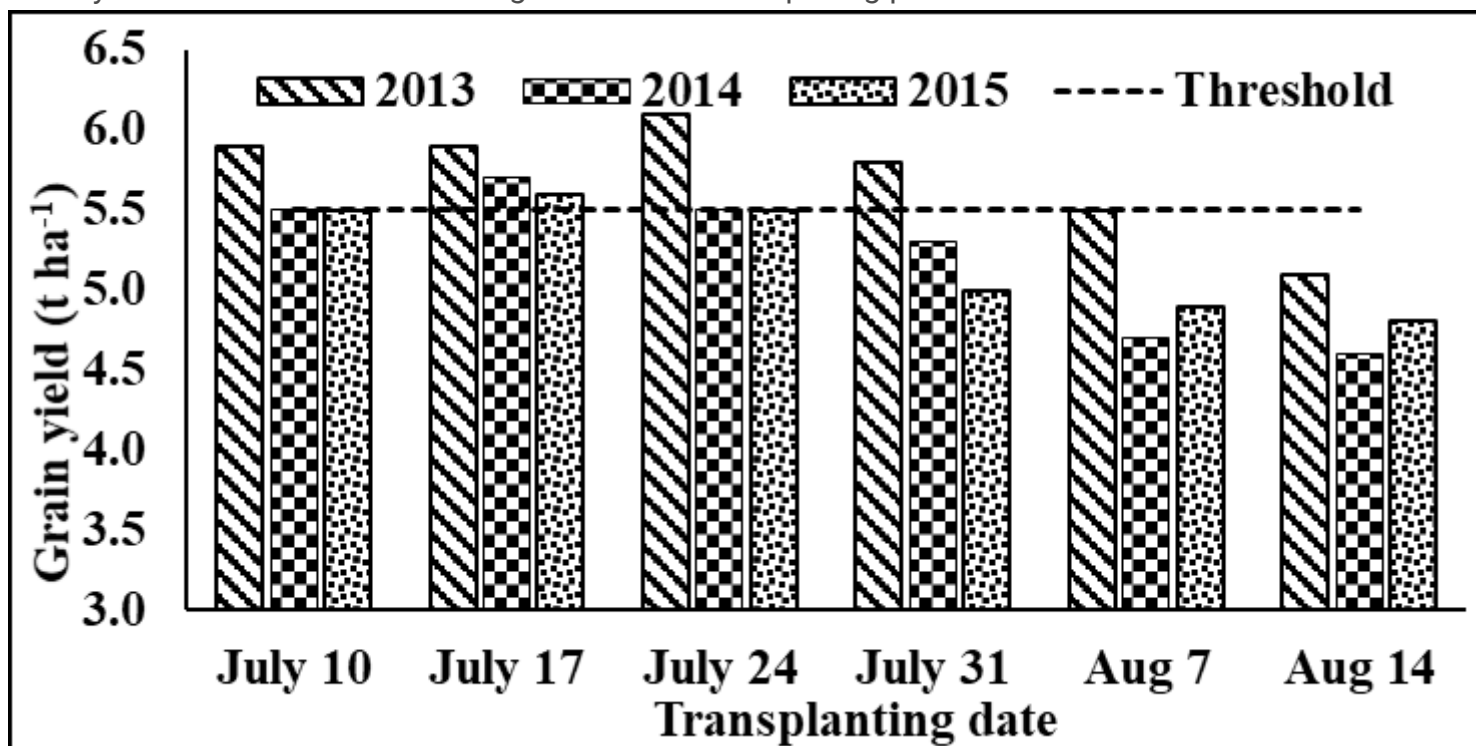


Figure 5

Yield performance of BR 11 over threshold under different transplanting date at Kushtia.

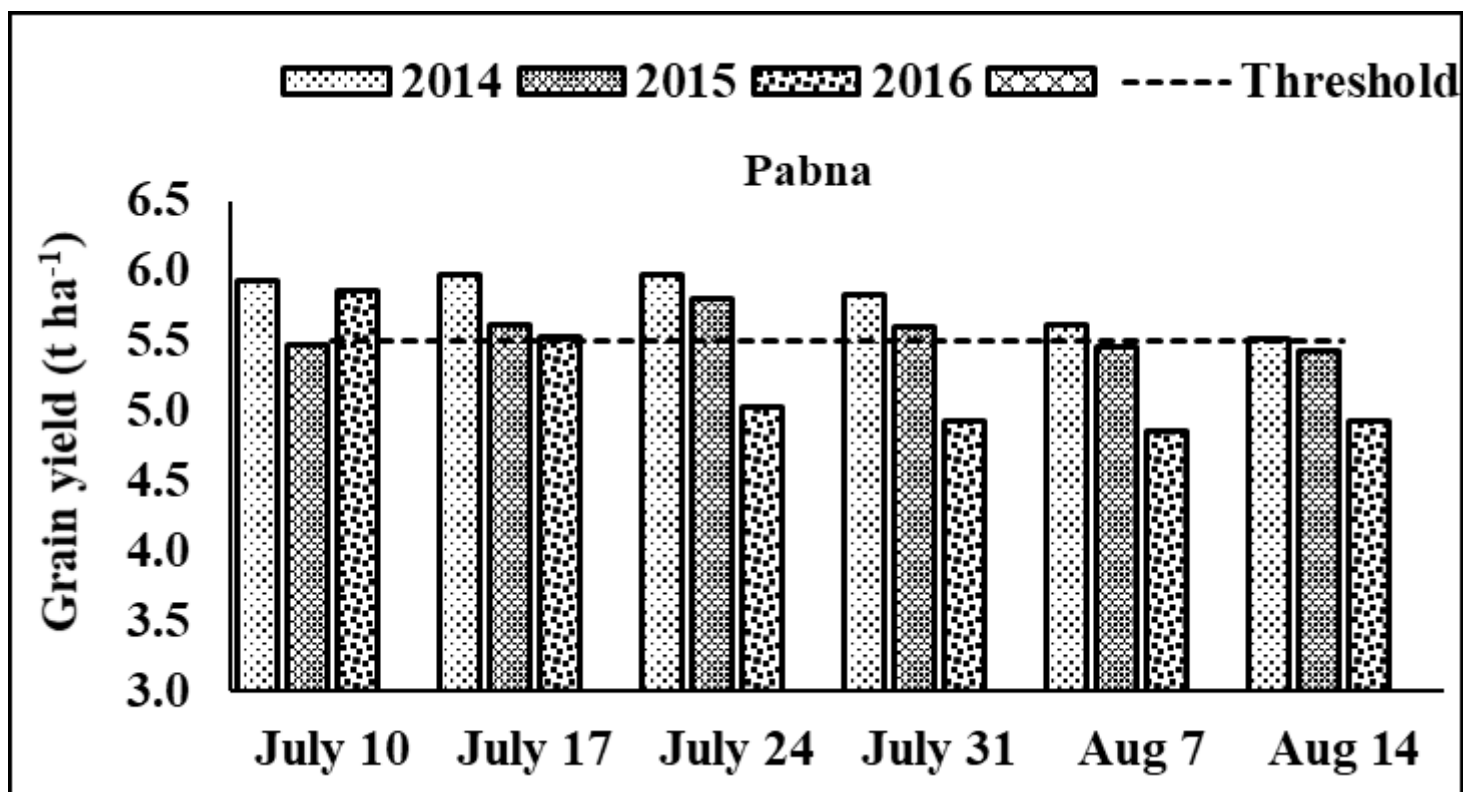


Figure 6

Yield performance of BR11 over threshold value at Pabna.

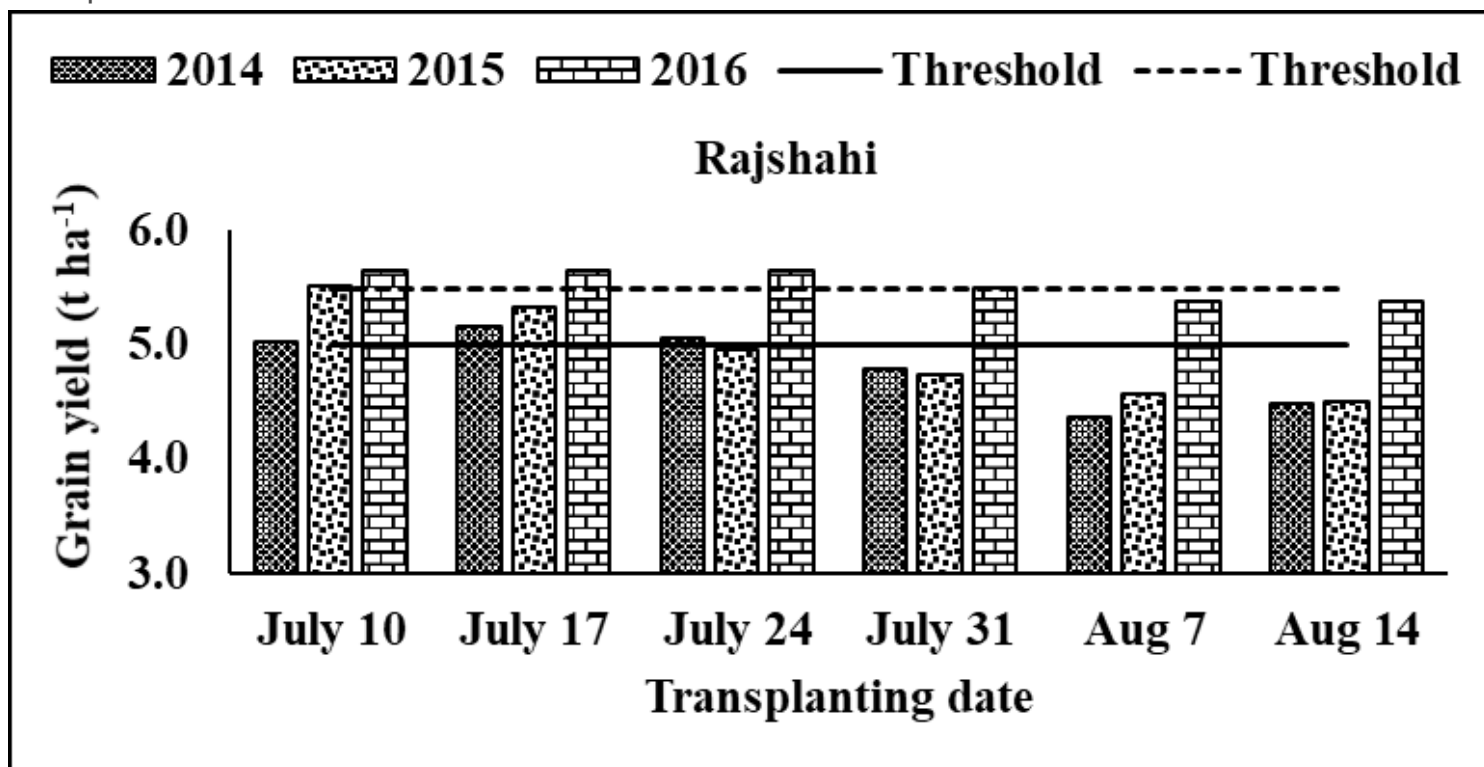


Figure 7

Yield performance of BR11 over threshold value at Rajshahi.