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Grain Yield and Water Productivity of Irrigated Rice Affected by Transplanting Dates in Bangladesh

M B Hossain[1]*, D Roy[1], M N H Mahmud[1], P L C Paul[1], M S Yesmin[1], P K Kundu[2], M T Islam[3] and A A Rim[4]

ABSTRACT

Selection of suitable transplanting window is essential for getting desired crop yield and optimizing irrigation water. This study was conducted in four different locations of Bangladesh (Gazipur, Mymensingh, Cumilla and Bogura districts) to investigate the effect of transplanting period on irrigation water productivity during irrigated rice (Boro) cultivation. Ceres-rice model incorporated in DSSAT was used to estimate rice grain yield and agronomic parameters for Boro 2016-17. Daily weather data and soil data were collected from Bangladesh Meteorological Department (BMD) and Soil Resource Development Institute (SRDI). The estimated irrigation scheduling using CROPWAT-8.0 model was used as input to the DSSAT model. Rainfall distribution showed only about 22% (2% in winter and 20% in pre-monsoon) of annual rainfall occurred in irrigated rice growing period. Delay transplanting after 15 December, the cultivar BRRI dhan28 faced higher mean daily temperature resulted shorter life span. The increased seasonal mean temperature by 2.8ºC in Gazipur and Bogura and 2.6ºC in Mymensingh and Cumilla from 15 December to 01 March reduced growth duration by 24 days in Gazipur, Mymensingh and Bogura and by 26 days in Cumilla district. Cumilla received the maximum rainfall, however Gazipur experienced the lowest among the four study locations. The received rainfall amount increased with the advancement of transplanting date from 15 December. The increased rainfall reduced the irrigation demand of the cultivar. On the contrary, reduced growth duration due to delay transplanting decreased the grain yield. Transplanting up to 1 February produced almost similar grain yield, while irrigation demand decreased from 15 December transplanting. Water productivity showed increasing trend for late transplanting. Considering grain yield and irrigation water productivity, 15 January to 1 February transplanting were found suitable transplanting period for the study locations. Rice crop establishment within the recommended period could be optimized the grain yield and irrigation water productivity in the selected study locations. Thus, maximum coverage of rainfall can be reduced the irrigation demand. Consequently, it may help to optimize groundwater use and to arrest the groundwater mining.

Key words: Irrigation, rainfall, transplanting date, Boro rice, water productivity

INTRODUCTION

Increasing irrigation water productivity is one of the main factors for water utilization during irrigated rice (Boro) cultivation. Rice (*Oryza sativa L.*) is the staple cereal in Bangladesh and Boro rice contributes 49.12% of total annual rice production (BBS, 2017). Low air temperature during winter branded Boro rice as long duration crop. Due to less rainfall in winter, Boro rice requires huge amount of irrigation water and other inputs compared to other seasons (Roy *et al.,* 2019). However, Bangladeshi farmers are habituated to grow Boro rice for its high yielding capacity. Modern varieties are highly reactive to water management, fertilizer doses and responsive to temperature during growth period.

According to IPCC (2007) projection, climate change may cause temperature rise as well as erratic rainfall pattern which will impact Bangladesh agriculture in the long run. Hence, crop evapotranspiration rate increases due to high temperature (Chaouche *et al.*, 2010), rice plant would need extra irrigation water to meet up the excess crop water requirement. However, increased temperature would reduce the rice growth duration.

[1]Senior Scientific Officer; [2]Scientific Officer; [3]Chief Scientific Officer, Irrigation and Water Management Division, Bangladesh Rice Research Institute (BRRI), Gazipur-1701, Bangladesh; [4]Soil Science Division, Bangladesh Rice Research Institute (BRRI), Gazipur 1701, Bangladesh.
*Corresponding author's E-mail: belal.iwm@gmail.com (M B Hossain)

Maniruzzaman *et al.,* (2018) noticed that elevated temperature in Bangladesh resulted yield loss and shorter growth duration of irrigated rice (Boro). Acharjee *et al.,* (2017) indicated that shorter growth duration reduced potential crop water requirement of Boro rice. Due to changing climate and intensive crop cultivation, water resources in Bangladesh are getting scared (Roy *et al.*, 2014). Rainfall shortage and increasing extreme rainfall event causing less surface water storage resulting less groundwater recharge. Thus, declining trend of groundwater is observed in most of the locations of Bangladesh (Hossain *et al.*, 2021). Ahmed *et al.,* (2004) reported rapid increase of arsenic contamination in the rice growing areas due to excess withdrawal of groundwater during Boro season. To feed the over increasing population of Bangladesh, contribution of Boro rice needs to be sustained. Thus, Boro rice production should be ensured with decreasing water use for irrigation. It could be expected that delay in Boro rice transplanting would reduce field duration of crop as well as crop water requirement. The rice water demand in later part of the growing period due to late transplanting would be fulfilled by pre-monsoon rainfall. Delayed transplanting of Boro rice up to a certain time limit may not cause significant yield loss. With this view, the study was undertaken with the following objectives as: i) to identify the effect of late transplanting on grain yield of irrigated rice and, ii) to determine the irrigation requirement and water productivity of Boro rice for shifting transplanting period.

METHODOLOGY

Study locations

The study locations consisted of four different districts Gazipur, Mymensingh, Cumilla and Bogura in Bangladesh. Each location situated in different agro-ecological zone (AEZ) with varying climate and soil. Figure 1 shows the study areas of Bangladesh. The minimum temperature showed increasing trend from January and reached its maximum in June after that it begins to decrease trend. Among the study areas Mymensingh experienced the lowest mean temperature, whereas the highest temperature was found in Gazipur and Bogura. The maximum rainfall occurred in July for all the locations.

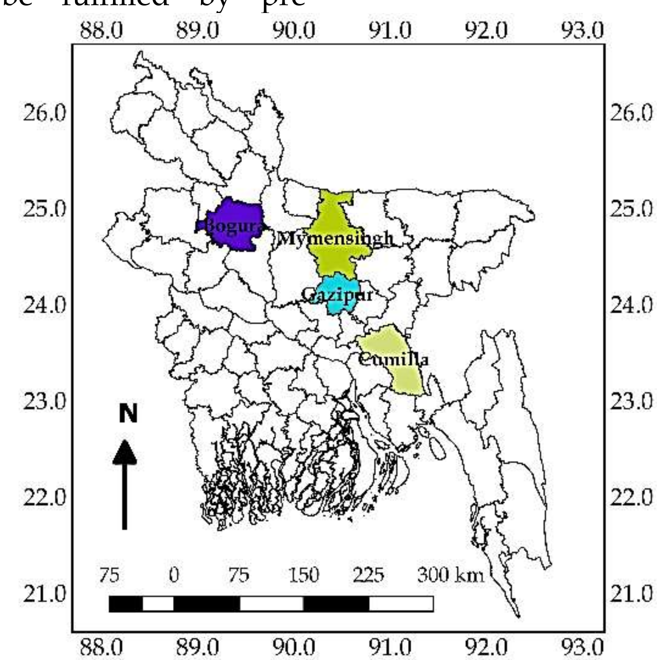

Fig. 1. Study area

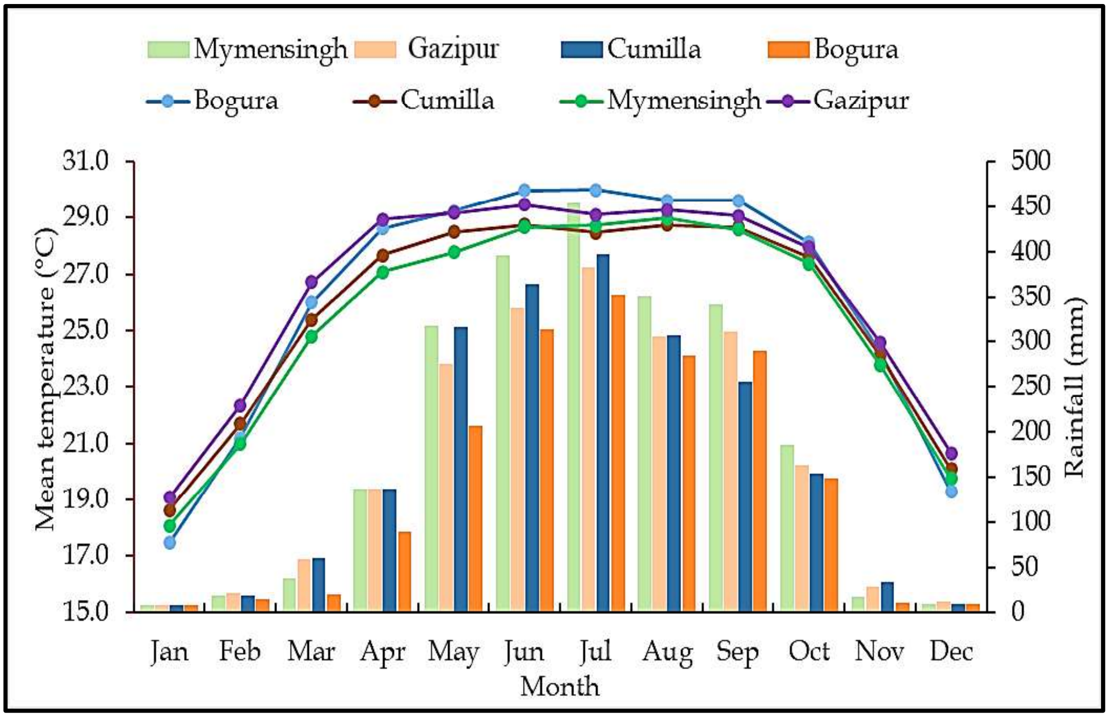

Fig. 2. Normal monthly mean temperature and rainfall (1981-2018) of the study areas.

Data Collection Model Parameterization

Weather and soil data

Historical daily weather data of maximum and minimum temperature, relative humidity, wind speed, bright sunshine hour and rainfall were collected from Bangladesh Meteorological Department (BMD). Required soil data of texture and particle size distribution, organic carbon, pH and nitrogen were collected from Soil Resource Development Institute (SRDI), Bangladesh. Ceres-rice model incorporated in Decision support system for agrotechnology transfer (DSSAT) model were adopted in this study. Weather and soil file for each study locations were made using the model as the input.

Cultivar selection

Bangladesh Rice Research Institute (BRRI) developed popular rice variety BRRI dhan28 were tested in four study locations. Average growth duration of BRRI dhan28 is 145 days with mean yield of 6.5 t ha^{-1} (Anonymous, 2020). Maniruzzaman *et al.*, (2017) identified the cultivar coefficient and we adopted it in our study. The cultivar coefficient was calibrated with the nitrogen fertilizer management experiment and validated with the genotype × environment interaction experiment. Table 1 shows the parameters of cultivar coefficient.

Table 1. Genetic coefficient of BRRI dhan28 for Bangladesh condition.

Cultivar	P1	P2O	P2R	P5	G1	G2	G3	G4	PHINT
BRRI dhan28	825	12.6	150	425	50	0.022	1.0	1.0	83

Where, P is time period in GDD (growing degree days) in °C above a base temperature from seedling emergence during which the rice plant is not responsive to changes in photoperiod. This period is also referred to as basic vegetative phase of the plant. P2O indicated critical photoperiod or the longest day length (in hours) at which the development occurs at a maximum rate, P2R was extent to which phasic development leading to panicle initiation is delayed (expressed as GDD in °C) for each hour increase in photoperiod above P2O, P5 indicated time period in GDD °C from beginning of grain filling to physiological maturity, G1 represented potential spikelet number coefficient as estimated from the number of spikelet per g of main culm dry weight, G2 is single grain weight (g) under ideal growing conditions, G3 is tillering coefficient (scaler value) relative to IR64 cultivar, G4 was temperature tolerance coefficient.

Model calibration and validation

For the model calibration, the observed grain yield and growth duration for varying transplanting time from 6 January to 22 February in 2016-17 and 2017-18 were compared with model simulated results. The field experiment was conducted at BRRI farm, Gazipur during Boro season. The model also validated by comparing simulated results with the observed grain yield of BRRI dhan28 from a multi-location trials conducted in the same year. The model performance was evaluated using normalized root mean square error (nRMSE), prediction error (P_e), coefficient of determination (R^2), degree of agreement (d). The equations for above mentioned statistical performance indicators are given below:

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

$$P_e = \frac{(P_i - O_i)}{O_i} \times 100 \quad (2)$$

$$R^2 = \left[\frac{\sum(O_i - \bar{O})(P_i - \bar{P})}{\sqrt{\sum(O_i - \bar{O})^2 \sum(P_i - \bar{P})^2}}\right]^2 \quad (3)$$

$$d = 1 - \frac{\sum_{i=1}^N (P_i - O_i)^2}{\sum_{i=1}^N (|P_i - \bar{O}| + |O_i - \bar{O}|)^2} \quad (4)$$

The coefficient of determination (R^2) value ranges from 0 to 1. The value close to 1 represents a good agreement while only the value greater than 0.5 is the acceptable limit for watershed simulations (Moriasi *et al.*, 2007). For nRMSE, excellent model simulation is found if the value 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 degree of agreement values (*d)* ranges between 0 and 1, where 0 indicates no agreement and 1 indicates a perfect agreement between predicted and observed data (Willmott, 1984).

Simulation of grain yield and growth duration

Rice grain yield and growth duration were estimated during Boro 2016-17 and 2017-18 for different transplanting periods. Four transplanting dates such as 6 January, 22 January, 6 February and 22 February were considered in this study. Forty-day-old rice seedlings were transplanted at a rate of 2-3 seedlings per hill. BRRI recommended urea fertilizer was applied @120 Kg-N in three equal splits.

Irrigation scheduling of rice

Irrigation was applied following alternate wetting and drying (AWD) irrigation practices. To do so, we utilized Food and Agriculture Organization (FAO) developed CROPWAT 8.0 model to determine the irrigation schedule of BRRI dhan28 for different transplanting dates. The model utilized maximum and minimum temperature, humidity, wind speed, sunshine hours, and rainfall to produce irrigation scheduling for rice crops. Then the estimated irrigation schedule for each transplanting date was used as input to the Ceres-rice model.

Growth duration, grain yield and water productivity

The seasonal mean temperature for each transplanting date was calculated for transplanting date and its relationship was developed to the crop growth duration. The amount of rainfall received by the crop and applied irrigation for each transplanting date were accounted. Finally, water productivity of rice was calculated from grain yield, rainfall and irrigation as shown in equation (i):

$$Irrigation\ water\ productivity\ (kg\ m^{-3}) = \frac{Grain\ yield\ (t\ ha^{-1}) \times 100}{Applied\ irrigation\ (mm)} \quad (i)$$

RESULTS AND DISCUSSION

Model calibration

Model simulated and field observed growth duration for different transplanting dates was analyzed (Table 2). For growth duration analysis, coefficient of determination (R^2) value was 0.79, normalize root mean square error (nRMSE) was below 10% and index of agreement value 0.83 indicated excellent model performance between simulated and observed field data of BRRI dhan28. Similar agreement was found for yield performance analysis (Table 3) where model simulated grain yield and field observed yield showed good agreement with R^2 value 0.65, nRMSE value 7.7 and d value 0.84.

Model validation

The validation of Ceres rice model was done with simulated and observed grain yield data during Boro, 2016-17 (Fig. 3) from a multi-location trial. Good model validation was found with nRMSE value 15.1, R^2 value 0.7 and 0.8 and d value 0.5 for grain yield of BRRI dhan28.

Rainfall distribution pattern

Figure 4 presents Annual rainfall of Gazipur, Cumilla, Mymensingh and Bogura which has been analysed. Among the study locations, the highest annual normal (37-year average) rainfall 2,270 mm was found in Mymensingh followed by 2,059 mm in Cumilla and 2,023 in Gazipur. However, the lowest 17,44 mm was observed in Bogura. All the study locations received comparatively higher rainfall than national average of 15,00-2,000 mm (Roy and Sattar, 2009). Seasonal rainfall distribution showed that rainfall occurrence is mostly season based and more than 60% of annual rainfall (66, 64%, 67% and 70% in Gazipur, Cumilla, Mymensingh and Bogura, respectively) was observed during monsoon (June to September) season (Figure 5). Biswas *et al.,* (2015) showed 92.7% total rainfall occurred during May to October in the northwest region of Bangladesh. Other than monsoon the second highest rainfall observed during pre-monsoon season followed by post monsoon season. Only 2% of total annual rainfall was observed in winter in all study locations.

Table 2. Simulated and observed grain yield and growth duration of BRRI dhan28 at Gazipur during Boro 2016-17 and 2017-18.

	Treatment	Growth duration (day)		nRMSE	R^2	d
		Simulated	Observed			
2016-17	06-Jan	137	138	5.66	0.79	0.83
	22-Jan	133	133			
	06-Feb	128	130			
	22-Feb	122	126			
2017-18	06-Jan	140	146			
	22-Jan	135	144			
	06-Feb	131	138			
	22-Feb	123	130			

Table 3. Simulated and observed grain yield and growth duration of BRRI dhan28 at Gazipur during Boro 2016-17 and 2017-18.

Year	Treatment	Grain yield (t ha^{-1})		nRMSE	R^2	d
		Simulated	Observed			
2016-17	06-Jan	5.53	5.74	7.7	0.65	0.84
	22-Jan	5.70	5.52			
	06-Feb	5.40	5.17			
	22-Feb	4.93	4.97			
2017-18	06-Jan	5.49	5.95			
	22-Jan	5.35	5.84			
	06-Feb	5.18	5.38			
	22-Feb	4.74	4.49			

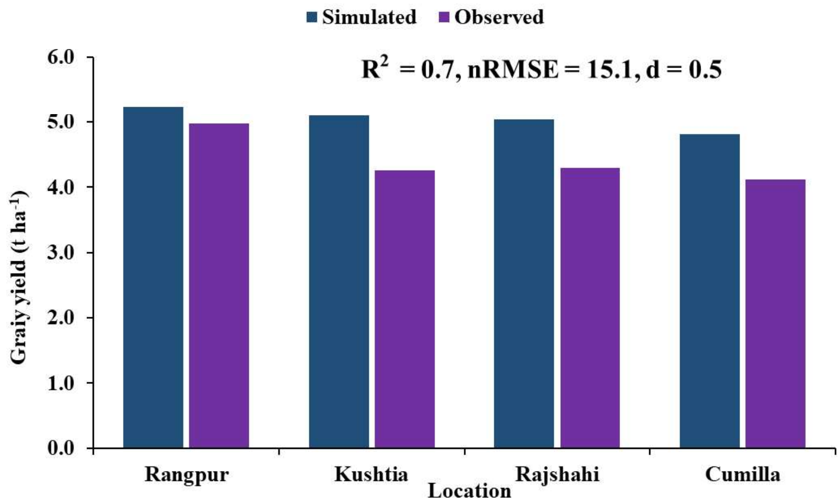

Fig. 3. Model simulated and observed grain yield of BRRI dhan28 in Rangpur, Kushtia, Rajshahi and Cumilla during Boro, 2016-17.

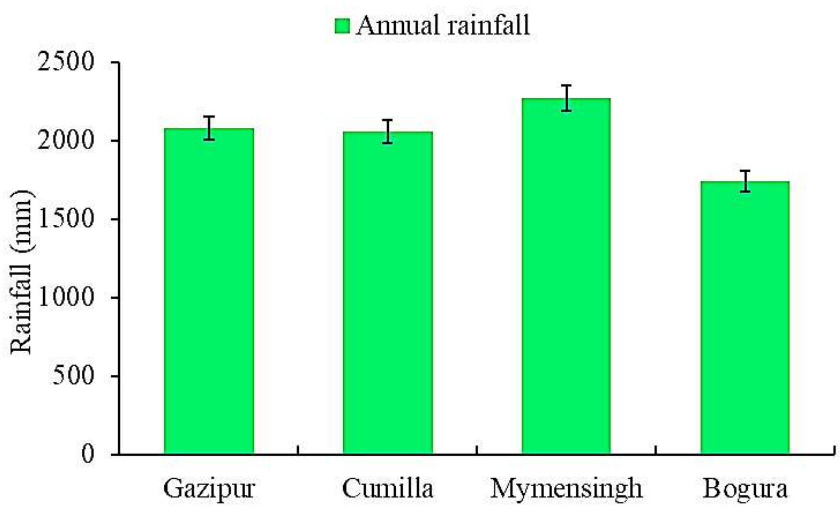

Fig. 4. Annual normal rainfall (mm) distribution of Gazipur, Cumilla, Mymensingh and Bogura (error bar indicates standard error).

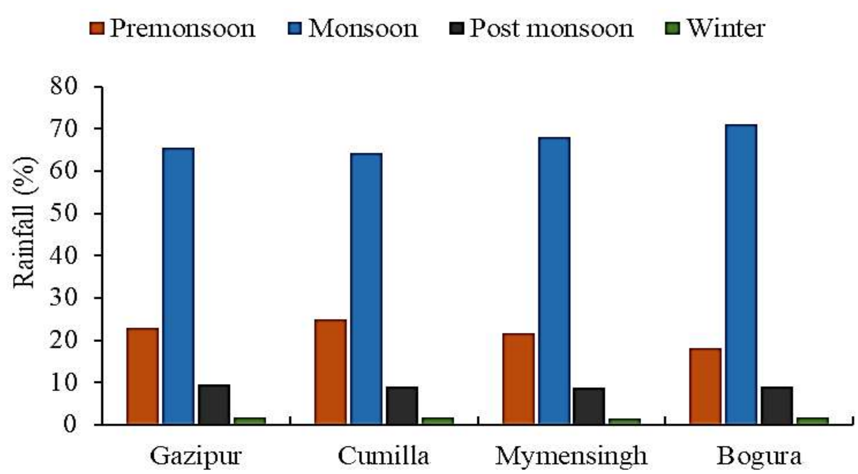

Fig. 5. Distribution of annual seasonal normal rainfall in the study locations.

Temperature effect on growth duration

Effect of seasonal mean temperature on growth duration of BRRI dhan28 on different locations was analysed (Fig. 6). Results showed that Gazipur faced the highest seasonal mean temperature followed by Cumilla and Bogura. Mymensingh received the lowest mean temperature for all the transplanting dates. Seasonal mean temperature showed the rising trend over delay transplanting than 15 December. Growth duration of BRRI dhan28 showed a decreasing trend over transplanting dates. The highest 152 days and the lowest 142 days growth duration of BRRI dhan28 was observed in Mymensingh and Gazipur, respectively for 15 December transplanting. This was the effect of the highest mean temperature 22.8ºC observed in Gazipur and the lowest 21.8ºC in Mymensingh. Delay transplanting of BRRI dhan28 from 15 December to 1 March increased temperature by 2.8ºC in Gazipur and Bogura and by 2.6ºC in Mymensingh and Cumilla. This increased temperature reduced the life span of the variety BRRI dhan28 by 24 days in Gazipur, Mymensingh and Bogura, and by 26 days in Cumilla district. This result was identical to Ahmed *et al.*, (2015) who found physiological maturity of BRRI dhan28 reduced by 14 to 16 days for delay sowing from 1 to 30 November in Jashore district. Maniruzzaman *et al.*, (2018) observed that growth duration of BRRI dhan28 reduced by 8, 7 and 10 days in Gazipur, Cumilla and Rajshahi respectively, for rising temperature by 1 ºC.

Rainfall coverage and rice irrigation water requirement for Boro rice

Boro rice cultivation starts in winter and matured in pre-monsoon season resulting high irrigation demand in its growing period. However, all the locations received considerable amount of rainfall during pre-monsoon. BRRI dhan28 experienced the lowest amount of rainfall water when it transplanted on 15 December. The received rainfall amount increased with the delay transplanting from 15 December. The spatial rainfall variation showed that Cumilla got the highest rainfall among the locations in all transplanting date except 1 March (Fig. 7). On the contrary, Gazipur received the lowest rainfall among the locations for all transplanting dates. The higher received rainfall reduced the irrigation demand as

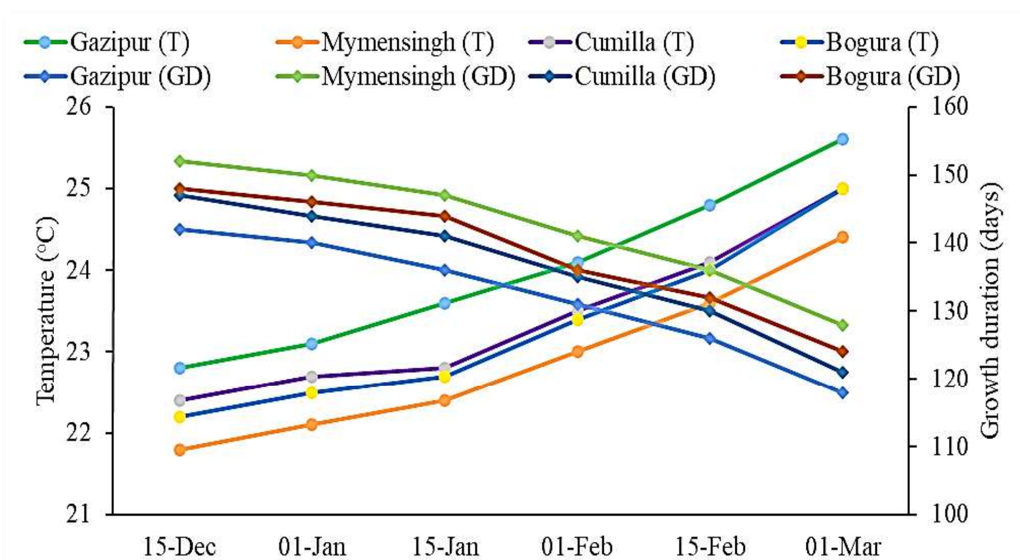

Fig. 6. Seasonal mean temperature effect on growth duration of BRRI dhan28 during Boro, 2016-17 in Gazipur, Mymensingh, Cumilla and Bogura. T indicates seasonal mean temperature and GD for growth duration.

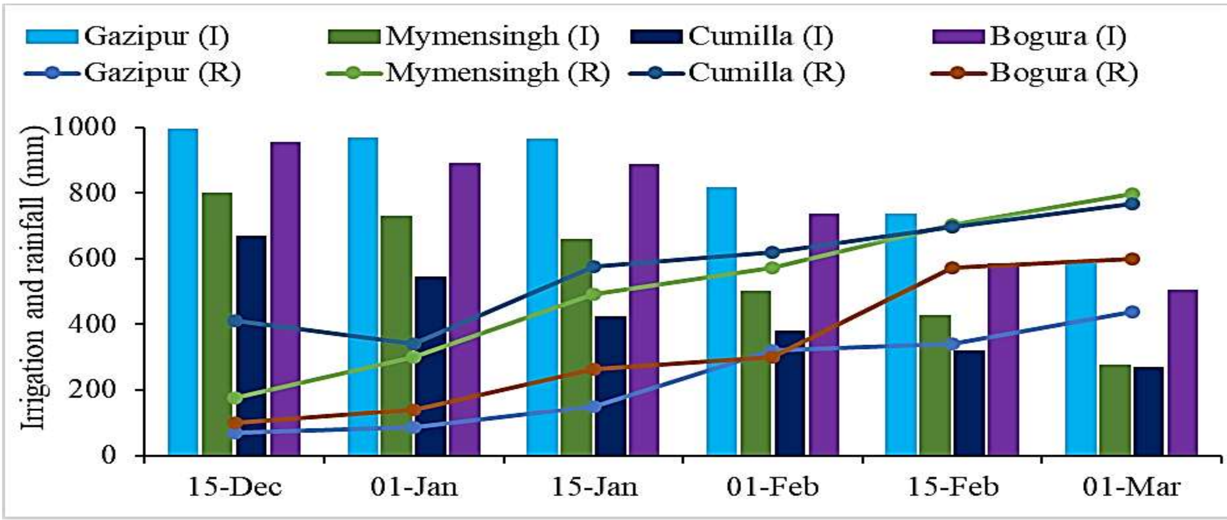

Fig. 7. Spatio-temporal variation of rainfall coverage and irrigation water requirement of BRRI dhan28 under different transplanting dates during Boro, 2016-17

rainfall met the consumptive use of rice. Hence, irrigation demand reduced with the delay transplanting in every location. The highest irrigation water (995 mm, 800 mm, 670 mm and 956 mm in Gazipur, Mymensingh, Cumilla and Bogura respectively) was applied for 15 December transplanting whereas 1 March transplanting required the lowest irrigation water (585 mm, 277, 272 and 507 mm in in Gazipur, Mymensingh, Cumilla and Bogura respectively).

Grain Yield performance and water productivity

Table 3 shows the spatio-temporal variation of grain yield of BRRI dhan28 under varying transplanting dates. It explained that yield potentiality of the cultivar decreased with the delay transplanting in all over the locations. This was due to the increased seasonal mean temperature reduced the growth duration as well as enhanced maturity of the variety. Among the locations, the highest grain yield was found in Mymensingh in all transplanting dates. In Mymensingh, 15 December to 15 January transplanting showed parallel grain yield performance (6.73 to 7.01 t ha^{-1}) and after that period yield reduction occurred. Similar yield was monitored both in Cumilla and Bogura for 15 December to 1 February transplanting. In Gazipur, the maximum grain yield was observed 5.25 t ha^{-1} for 1 January transplanting; however, similar yield was recorded for 15 December (5.23 t ha^{-1}) 15 January (5.02 t ha^{-1}) and 1 February (5.1 t ha^{-1}) transplanting. These results were found identical to Roy *et al.,* (2019) who found the decreasing yield over delay transplanting of BRRI dhan28. Yesmin *et al.,* (2019) noticed 15 November to 15 December the best sowing window for BRRI dhan28 at Amtali, Barguna area considering grain yield.

Delay transplanting increased the irrigation water productivity of Boro rice. This is due to the more rainfall accumulation in the late planting condition reduced the irrigation water demand. In Gazipur, the maximum irrigation water productivity was found on 1 February transplanting and that was minimum in 15 December transplanting. In the other locations, 1 March transplanting showed the maximum irrigation water productivity (1.98, 1.55 and 0.83 kg m^{-3} in Mymensingh, Cumilla and Bogura, respectively). The lowest 0.84, 0.82 and 0.58 kg m^{-3} irrigation water productivity was monitored in Mymensingh, Cumilla and Bogura, respectively for 15 December transplanting.

Table 4. Grain yield and water productivity of BRRI dhan28 in the study locations during Boro 2016-17.

Transplanting date	Grain yield (t ha^{-1})				WP (kg m^{-3})			
	Gazipur	Mymensingh	Cumilla	Bogura	Gazipur	Mymensingh	Cumilla	Bogura
15-Dec	5.25	6.73	5.49	5.53	0.53	0.84	0.82	0.58
01-Jan	5.23	7.01	5.62	6.07	0.54	0.96	1.03	0.68
15-Jan	5.02	6.84	5.58	5.99	0.52	1.04	1.31	0.67
01-Feb	5.10	6.20	5.11	5.55	0.62	1.23	1.34	0.75
15-Feb	4.19	6.18	4.94	4.24	0.57	1.45	1.54	0.72
01-Mar	3.16	5.49	4.22	4.20	0.54	1.98	1.55	0.83

CONCLUSION

Rainfall occurrence in Gazipur, Mymensingh, Cumilla and Bogura district of Bangladesh is mostly seasonal and more than 60% of total rainfall occurred during monsoon (June to September). Around 20% of annual rainfall received during pre-monsoon, however only 2% found in Winter. This resulted high irrigation demand in Boro rice cultivation. Delay transplanting of BRRI dhan28 from 15 December to 1 March faced increased temperature by 2.8^{o}C in Gazipur and Bogura and by 2.6^{o}C in Mymensingh and Cumilla. Consequently, this increased temperature reduced the life span of the variety by 24 days in Gazipur, Mymensingh and Bogura and by 26 days in Cumilla district. Besides, higher rainfall incidence reduced the irrigation demand in late transplanting condition. Mymensingh region showed the best yield performance among the locations where grain yield declined after 15 January transplanting. Similar trend was noticed in Cumilla and Bogura. The maximum grain yield was observed on 1 January transplanting; however, similar yield was recorded for 15 December to 1 February transplanting in Gazipur. Considering temperature, rainfall and irrigation water availability, 15 January to 1 February transplanting was found suitable transplanting period for the study locations.

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