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Irrigation Requirement and Possibility of High-temperature Stress of Wheat for Different Planting Dates under Climate Change in Bogura, Bangladesh

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ABSTRACT

Understanding the changes in irrigation requirement and possibility of high-temperature stress on major crops are essential for food security of Bangladesh. Different water requirement components-including potential crop water requirement and potential irrigation requirement were estimated for early (20 October), normal (10 November), and late (01 December) planting dates of wheat in Bogura district, Bangladesh using daily observed climate data in CropWat model for 1980–2013 time period. Significant decreasing trends of reference crop evapotranspiration were found during wheat growing months (October to March) because of changes in climatic conditions. Potential crop water requirement and irrigation requirement showed significant decreasing trends. The estimated rate of potential irrigation requirement by Sen's slope estimation method showed a decreasing trend (1.44, 1.35, and 0.84 mm/year for early, normal, and late planting, respectively). The average potential irrigation requirement for early planting was only 1.9 mm less compared to normal planting, while for late planting was 32.5 mm higher. High-temperature stress (maximum temperature above 25±5°C and 30±5°C during reproductive (mid-season) and maturing stage (late season), respectively) was evident during maturing stage under late planting and during reproductive phase for all planting dates of wheat. Increasing number of high-temperature days for late planting and decreasing number of high-temperature days for early and normal planting were observed during 1980–2013. Therefore, recent climate change-induced high-temperature stress adversely affected wheat cultivation only under late planting conditions. However, climatic water demand did not impose any additional pressure on available water resources during the last three decades.

Introduction

Wheat is a crucial *Rabi* season crop in Bangladesh. The national consumption of wheat in Bangladesh is about fourfold higher than average annual domestic production. The consumption rate of wheat products is increasing day by day because of moderate cultivation cost, reasonable market price and nutrition level of wheat (Kamrozzaman *et al.,* 2016). Therefore, it is essential to increase domestic wheat production to meet the national demand and reduce the share of imported wheat. However, it will be a big challenge in the coming days to increase wheat production, especially in drought-prone areas. The drought-prone regions of Bangladesh are now drier and warmer than they were fifty years ago, and recent climate change projections suggest that the country will become hotter and it will experience frequent drought events due to increased uneven monthly rainfall distribution (Selvaraju and Baas, 2007). A study carried out on current climate change in Bangladesh recording temperature and rainfall data from 17 meteorological stations during 1958–2007 by Shahid (2010) indicates a significant increase in winter teamperature than summer. Agrawala *et al.* (2003) also reported the same phenomena, more warming in winter compared to summer in Bangladesh. Climate change may negatively affect wheat grain yields, primarily because of increased temperature and water stress. According to Poulton and Rawson (2011), temperature in Bangladesh has increased over the past two decades by 0.035°C per year. If this trend continues, temperature will have increased 2.13°C more than 1990 levels by 2050 (Uddin *et al.*, 2015). Rise in 4°C temperature would significantly decrease crop production, about 68% for wheat (Karim *et al.*, 1999). Although carbon di-oxide fertilization facilitates grain production, doubling the atmospheric CO_2 concentration in combination with a 4°C rise in temperature would result into an overall 31% decline in wheat production (Karim *et al.*, 1999). Not only

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the crop production, but also the water demand for irrigation is susceptible to climate change (Schlenker *et al*., 2007). The increased temperature usually rises the climatic water requirement of crops. It is essential to know the amount of irrigation required for a crop and the changes in irrigation demand with changes in climatic conditions for the long-term sustainable cultivation of that crop. Water deficit reduces the net photosynthesis rate, transpiration rate, and stomatal conductance both at anthesis and grain-filling stages of wheat (Bogale, 2011). According to Lal *et al*. (1998), the combination of acute water shortage and thermal stress adversely affects the wheat in India even under the positive effects of elevated CO_2 in the future.

Temperature requirement of wheat usually varies from one variety to another. However, the optimum temperature for wheat growth varies from 20 to 25°C depending on type of cultivars. High temperature (above 25 to 30°C) significantly decreases grain yield, kernel weight, and grain filling duration of wheat (Modarresi *et al.*, 2010). The maximum temperature that detrimentally affects wheat growth is 35°C. At different stages of plant growth and development, wheat requires different optimum temperatures. The optimum temperature during the anthesis and grain filling period of wheat ranges from 12 to 22°C and exposure above this temperature can significantly affect the growth and yield of wheat (Tewolde *et al*., 2006; Fisher, 2007). Heat stress after the anthesis period in wheat results in smaller grain weight because of reduced duration of grain filling and starch synthesis period (Hasan and Ahmed, 2005). The grain filling of wheat is significantly impeded by heat stress due to reduced current leaf and ear photosynthesis (Blum *et al.*, 1994).

Climatic variability has influenced crop's sowing date, growth duration, yield, and susceptibility to stress conditions, like heat-stress in the long-run. Australia is an example which is facing challenges in sustainable wheat production due to the influence of climate change (You *et al.,* 2009 and Luo *et al.* 2018). Understanding the influence of planting date and associated water and heat stress helps develop adaptation strategies under climate change. Late planting of dry season Boro rice can substantially reduce irrigation requirement by increasing effective rainfall during the growing season, but the option is minimal due to both day- and night-time heat stress (Acharjee *et al.*, 2019). However, for different crops, the influence of shifting planting/sowing dates would be distinct. Among various agronomic factors responsible for the low yield of wheat in Bangladesh, planting/sowing date and varietal selection are of primary importance. The variations in yield and growth characteristics of wheat due to variation in sowing date were reported by Hasina *et al*. (2012) and Fisher (2007). Plant growth characteristics and yield are significantly differed by wheat sowing dates in Bangladesh (Uddin *et al.*, 2015). In recent years, an alarming fact, particularly in Bogura district, is the rapid and continuous reduction in wheat cultivation area. *Rabi* season wheat farmers are shifting towards the cultivation of other non-rice grain crops and vegetables. The total wheat cultivation area in Bogura was 23472, 22974, 2841 and 2677 hectares during 1988, 1998, 2008 and 2018, respectively (BBS, 2013; BBS, 2019; Chowdhury and Zulfikar, 2001). It is essential to investigate whether the recent reduction in wheat cultivation area is because of current climate change-induced stress conditions or not. Therefore, this paper focused on understanding the recent changes in water requirement components and possible low/high-temperature stress based on observed changes in climatic parameters in Bogura.

Materials and Methods

Study area

The study was conducted for Bogura district, which is situated (24.85° N, 89.37° E) in the Northwest part of Bangladesh. A portion of the Bogura district is under the Barind region, the largest Pleistocene physiographic unit of the Bengal Basin (Hossain et al. 2016). Bogura district has a humid sub-tropical climate and the annual average rainfall (1,971 mm) is relatively minor in this region (Nasher and Uddin*,* 2014 and Nury *et al.,* 2017). This region has already been designated as a drought-prone area. Its average temperature ranges from 35°C to 25°C in the hottest season and 9°C to 15°C in the coolest season (Banglapedia, 2014). The area comprising Sariakandi, Gabtali, and Sonatala Upazilas and major part of Dhunat Upazila in Bogura is called the eastern alluvial tract. Fertilized by the silt of floodwaters, the eastern alluvion is one of the most fertile and prosperous areas in Bogura. Jute, aus and aman paddy, wheat, sugarcane, and pulses are grown in this area.

Data collection

Daily climate data of Bogura district on maximum and minimum temperature, relative humidity, wind speed, and sun shine hour from 1979 to 2013 were collected from Bangladesh Meteorological Department. Required crop data, including crop-coefficient values, growth stage duration, rooting depth, critical depletion, yield response factor, and crop height, were collected from Bangladesh Agricultural Research Institute. General soil data for the average soil type of Bogura were available from FAO.

Estimation of irrigation requirement

Water requirement components of wheat from 1980 to 2013 in Bogura were estimated using the FAO developed CropWat 8.0. This model calculates the irrigation water requirement of crops and soil-water balance following Allen *et al*. (1998). The following equation represents the estimated net irrigation requirement:

$$PIR = \sum ET_C - ER + PL$$

Where, PIR is the potential irrigation requirement, $\sum ET_C$ is the total crop evapotranspiration, ER is the effective rainfall during wheat growing duration and PL is the amount of percolation loss.

Daily reference crop evapotranspiration (ET_O) was estimated in CropWat following the FAO Penman-Monteith formula using the daily climate data. Potential crop water requirement, effective rainfall during the growth period, potential irrigation requirement and rainfed yield loss of wheat were estimated for early (20 October), normal (10 November), and late planting (01 December) of wheat (Figure 1). The followed irrigation was scheduled to estimate the potential irrigation requirement to irrigate the wheat fields at 20 mm depletion of soil water to refill at 100% field capacity. The Soil Conservation Service method was followed in CropWat for estimating effective rainfall during wheat growth period.

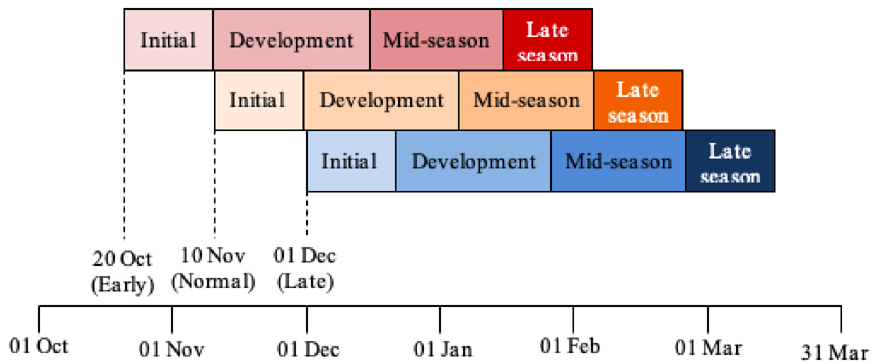

Figure 1. Planting date and dates of different growth stages of wheat under early, normal and late plantings

Analysis of the possibility of low- and high-temperature stress

The number of days below a range of critical minimum temperature (10±5°C) during the initial stage of wheat and above a range of critical maximum temperature during reproductive (25±5°C) and maturing stage (30±5°C) of wheat were counted for early, normal and late planting of wheat in Bogura during 1980 to 2013. The percent critical days of initial, reproductive, and maturing stage were estimated taking into account the total number of days in initial, mid-season, and late season, respectively.

Trend analysis

Mann-Kendall test and Sen's slope estimation method were applied to identify the trends and rate of changes in monthly reference crop evapotranspiration, rainfall, and rainfall deficit. Also, the Mann-Kendall trends were estimated for monthly maximum and minimum temperature, relative humidity, wind speed, sunshine hour, and radiation. The non-parametric Mann-Kendall test is used for testing the presence of a monotonic increasing or decreasing trend. The non-parametric Sen's method is used for estimating the slope of a linear trend, i.e. determining the magnitude of the trend. Mann-Kendall test and Sen's slope estimation method were applied to identify the trends and rate of changes in potential crop water requirement, effective rainfall, potential irrigation requirement, and rainfed yield loss (Sen, 1968). Furthermore, these trend analysis methods were also applied to understand the changes in number of high-temperature stress days of wheat in Bogura.

Results and Discussion

Trends of reference crop evapotranspiration and climatic parameters

The estimated reference crop evapotranspiration showed declining trends in all wheat growth months, i.e., during October to March in Bogura (Table 1). Acharjee *et al.* (2017a) also indicated significant decreasing trends of reference crop evapotranspiration in most dry months in Northwest Bangladesh. The significant declining trends in all of the wheat-growing months, except October indicate a noticeable decline in climatic water requirements of crops grown during *Rabi* season. The rate of decrease in ET_O is highest in March and January, –0.024 and –0.021, respectively in comparison to other months.

The decreasing trends of rainfall during the *Rabi* season indicate decreased availability of water due to climate change. However, the decreasing trend of rainfall is non-significant in most of the *Rabi* months. The rainfall deficit showed decreasing trends during the *Rabi* months. The decreasing trend of rainfall deficit is only significant in January because of a substantial decrease in reference crop evapotranspiration (–4.93***) instead of some reduce in rainfall (–0.74). Increasing trends of rainfall deficit during October indicates that early planting of wheat may account for increasing water demand in Bogura. To understand the changes in reference crop evapotranspiration, it is important to identify the trends of climatic parameters. The trends of maximum temperature during *Rabi* season indicate a decrease in most of the months, except October and February. However, the trend of maximum temperature is significant only in January. The minimum temperature trends during *Rabi* season indicate an increase in most of the months and a significant increase only in February and March. Increasing trends of relative humidity and decreasing trends of wind speed were found. The sunshine hours during *Rabi* season indicate significant decreasing trends in all of the months. Although the increase of minimum temperature contributes to increased reference crop evapotranspiration, a decrease of maximum temperature in some of the months, increased relative humidity, decreased wind speed, and sunshine hours in *Rabi* season ultimately resulted in a reduced reference crop evapotranspiration in Bogura. Therefore, ET_O may decrease under some increased temperature due to changes in other climatic parameters.

Table 1. Mann-Kendall test values, i.e Z-statistics and Sen's slope of monthly average reference crop evapotranspiration (ET_O), monthly total rainfall and rainfall deficit in Bogura from 1979 to 2013

Months	Monthly average ET_O		Monthly total rainfall		Monthly rainfall deficit	
	Z-statistics	Sen's slope	Z-statistics	Sen's slope	Z-statistics	Sen's slope
January	**–4.93*** **	–0.021	–0.74	0.000	**–3.12** **	–0.634
February	**–2.07***	–0.009	–1.49	–0.143	–0.26	–0.055
March	**–3.38*** **	–0.024	–0.81	–0.111	–1.48	–0.778
April	**–3.40*** **	–0.029	–0.48	–0.563	–0.41	–0.426
May	–0.70	–0.007	–1.72+	–3.000	1.28	2.480
June	–1.88+	–0.009	–0.40	–1.143	0.06	0.244
July	**2.09***	0.012	**–2.36***	–6.588	**2.30***	6.910
August	–0.91	–0.005	0.01	0.000	–0.31	–0.233
September	0.28	0.002	–1.35	–3.286	1.04	2.500
October	–1.38	–0.008	0.81	1.714	–0.80	–1.805
November	**–3.78*** **	–0.012	–0.51	0.000	–1.90+	–0.355
December	**–2.70** **	–0.015	**–2.53***	–0.032	–1.29	–0.334

+, *, ** and *** signs indicate significant at 0.10, 0.05, 0.01 and 0.001 level of significance, respectively

Table 2. Mann-Kendall test values, i.e. Z-statistics of monthly minimum and maximum temperatures, sunshine hours, relative humidity and wind speed in Bogura during wheat growing months (October–March) from 1979 to 2013

Months	Z-statistics				
	Minimum temperature	Maximum temperature	Sunshine hours	Relative humidity	Wind speed
January	–1.48	**–3.64*** **	**–5.36*** **	**3.24** **	–1.07
February	**2.26***	1.73+	**–2.95** **	1.86+	–1.52
March	**2.69** **	–0.41	**–3.85*** **	**3.35*** **	**–1.97***
October	1.53	1.37	**–2.00***	–0.67	–1.32
November	1.09	–0.34	**–3.21** **	0.21	**–3.34*** **
December	0.83	–1.15	**–3.37*** **	**2.15***	**–3.23** **

+, *, ** and *** signs indicate significant at 0.10, 0.05, 0.01 and 0.001 level of significance, respectively

Trends of changes in irrigation requirements of wheat

The estimated Sen's slope of potential crop water requirement and irrigation requirement of wheat showed decreasing trends for all planting in Bogura from 1980 to 2013 (Figure 2). Sen's rate of decrease of potential crop water requirement was 1.48, 1.46, and 1.14 mm/year for early, normal, and late planting, respectively. Sen's rate of decrease of potential irrigation requirement was 1.44, 1.35, and 0.84 mm/year for early, normal, and late planting, respectively. Jahan *et al.* (2010) also indicated that the reference crop evapotranspiration, potential crop water requirement, and net irrigation requirement generally has decreased uring 1980–2006 in the Northwest part of Bangladesh. The estimation of Mann-Kendall trend values indicates statistically significant decreasing trends of potential crop water requirement and irrigation requirement of wheat for all planting dates (Table 3).

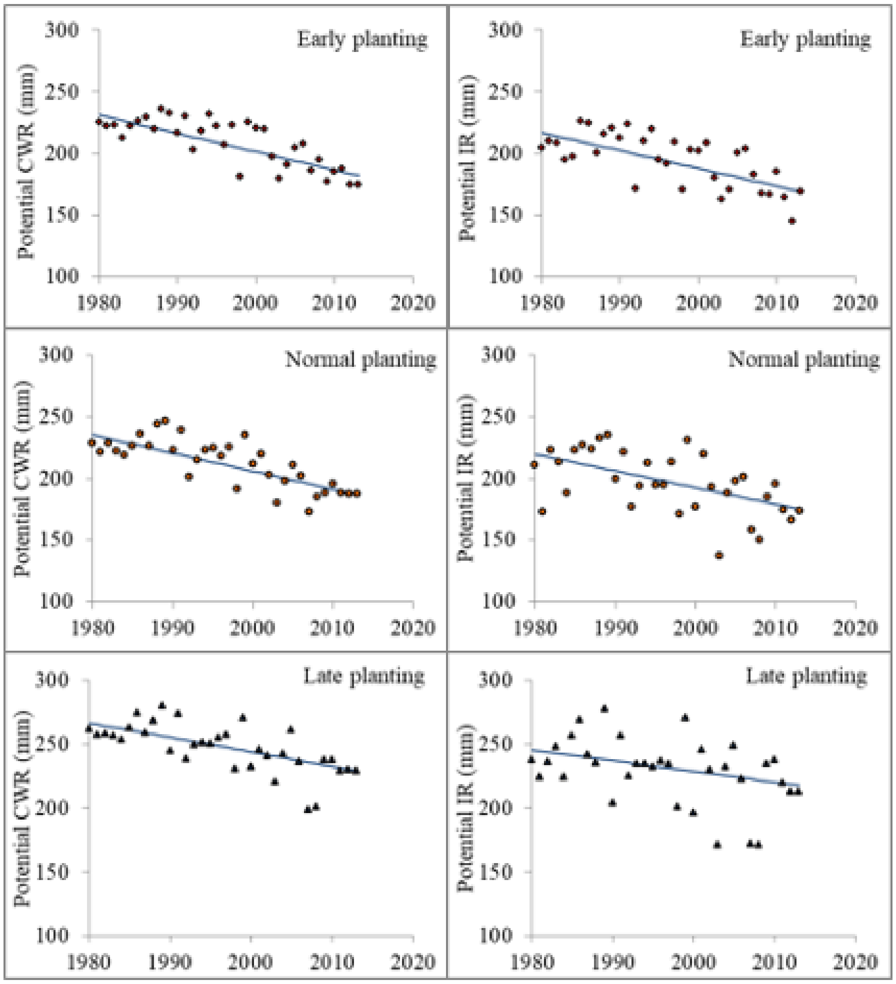

Figure 2. Sen's slope of potential crop water requirement (CWR) and irrigation requirement (IR) of wheat for early, normal and late planting in Bogura from 1980 to 2013.

Table 3. Mann-Kendall test values, i.e. Z-statistics and Sen's slope of potential crop water requirement, effective rainfall during crop growth period and irrigation requirement of wheat under early, normal and late planting in Bogura from 1980 to 2013

Parameters	Z-statistics			Sen's slope		
	Early planting	Normal planting	Late planting	Early planting	Normal planting	Late planting
Potential crop water requirement	**−4.51*** **	**−4.61*** **	**−4.21*** **	−1.484	−4.61	−4.21
Effective rainfall	−0.39	−0.21	−0.85	−0.055	−0.21	−0.85
Irrigation requirement	**−4.09*** **	**−2.98** **	**−2.40* **	−1.442	−2.98	−2.40
Rain-fed yield loss	−0.85	−1.17	−0.62	−0.113	−1.17	−0.62

*, ** and *** signs indicate significant at 0.05, 0.01 and 0.001 level of significance, respectively.

The trends of effective rainfall during the growth period of wheat showed non-significant decreasing trends for all planting dates. The highest declining trends of potential irrigation requirement were found for the early planting of wheat. For late planting of wheat, the potential crop water requirement and irrigation requirement showed a 34.34 and 32.49 mm increase compared to normal planting on an average for the study years (Figure 3). In percentage, the potential irrigation requirement for early planting is 0.4% less and late planting is 16.95% more compared to normal planting time. However, the amount of decrease in potential crop water requirement and irrigation requirement for early planting compared to normal planting is comparatively less than the increase in late planting. The results also indicate that though early planting reduced the availability of effective rainfall during the growth period of wheat, still early planting option reduced the irrigation requirement of wheat by some amount because of reduction in potential crop water requirement. Also, the amount of increase in effective rainfall for late planting is very low compared to the rise in potential crop water requirement.

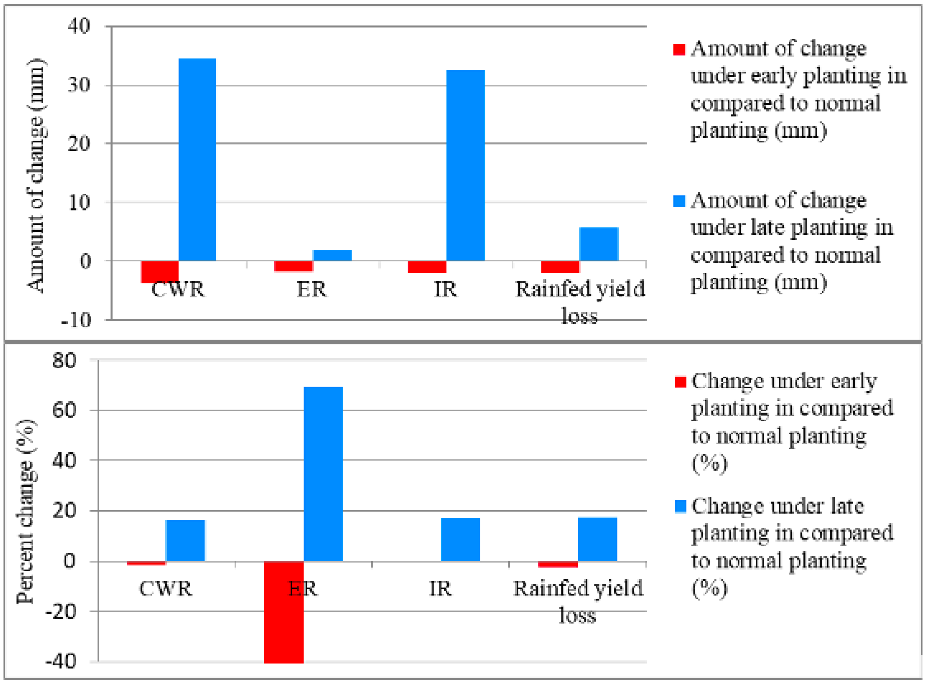

Figure 3. Average amount and percent change of potential crop water requirement (CWR), effective rainfall during crop growth, potential irrigation requirement and rainfed yield loss of wheat under early and late planting compared to normal planting in Bogura during 1980–2013

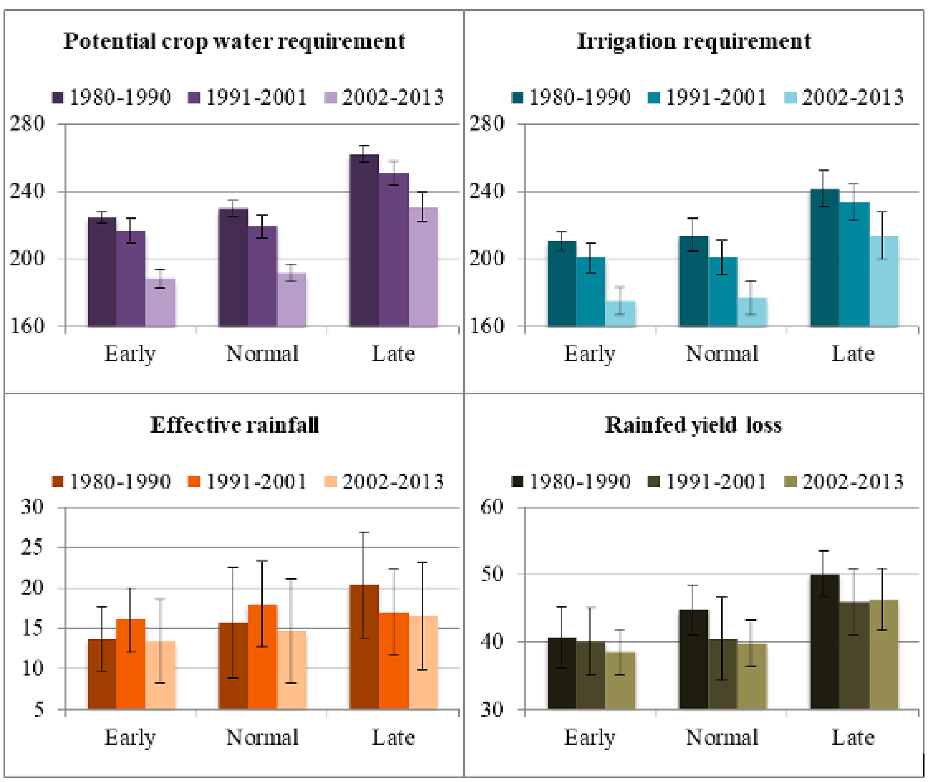

Figure 4. Average amount (bars) and variation (error bars) of potential crop water requirement, irrigation requirement, effective rainfall and rainfed yield loss of wheat in Bogura during last three decades

Therefore, climate change-induced changes in climatic water requirement of wheat play a major role in determining irrigation requirement than any changes in rainfall for wheat and possible for other *Rabi* season non-rice crops. The analysis of changes in water requirement components during the last three decades indicate a consistent shift in potential crop water requirement and irrigation requirement (Figure 4) for all planting dates. However, effective rainfall changes, especially during early and normal planting, do not depict a consistent change throughout three decades. Also, the variations in effective rainfall estimates were much higher in comparison to irrigation requirements. Changes in rainfed yield loss were consistent throughout three decades under early and normal planting, but not under late planting of wheat. This study has not considered the possible changes in the growth stage duration of wheat during recent decades. Crop's phenological response to increased temperature reduces the number of growing days that reduce irrigation demand (Acharjee et al., 2017b). Therefore, considering changes in growth duration would further reduce the amount of irrigation requirement than estimated in this study.

Changes in low- and high-temperature stress days during wheat growth period

Figure 5 illustrates the percent critical days of possible cold stress at a minimum temperature below 10±5°C during the initial stage and high-temperature stress at a maximum temperature above 25±5°C and 30±5°C during reproductive (mid-season) and maturing stage (late season) of wheat, respectively. Results indicate no possibility of cold stress for wheat varieties that are sensitive to <10°C temperature and a very low chance of cold stress for wheat varieties sensitive to <15°C temperature cold stress. Late planting showed more possibility of cold stress than normal planting of wheat because of receiving the lowest minimum temperature in December. Early planting showed no evidence of cold stress, even for 15°C minimum temperature-sensitive varieties. Therefore, early planting of wheat could be an effective option to avoid cold stress during germination.

The number of high-temperature stress days, in percent of total mid-season days, during the reproductive phase is very high (>33% for all planting dates) for wheat varieties that cannot withstand temperature above 20–26°C (Figure 5). The number of high-temperature stress days during the mid-season is even very high under late planting wheat varieties that can withstand less than 28°C. Hossain and DA SILVA (2012) also indicated that all current wheat varieties, when planted late, become exposed to severe temperature stress that significantly affected the growth and yield.

Temperature above 25°C during the reproductive phase detrimentally affects the wheat growth and reduces grain yield (Hossain *et al.*, 2011; Hossain *et al.*, 2012). Normal planting dates showed the least possibility of high-temperature days during the reproductive phase of wheat. Moreover, the Mann-Kendall test values of the number of days with maximum temperature above 25°C during the reproductive stage for normal planting showed a significant decreasing trend (Table 4). The Mann-Kendall test values of the number of days with maximum temperature above 25°C during the reproductive phase for early or late planting showed non-significant decreasing trends. Therefore, normal planting date could be the best option to avoid high-temperature stress during the reproductive phase of wheat.

The number of high-temperature stress days, in percent of total late-season days, during the maturing stage is very high (>33% for normal and late planting) for wheat varieties that cannot withstand temperature above 25–28°C (Figure 5). The number of high-temperature stress days during the late season is even very high under late planting for wheat varieties that can withstand less than 31°C. Temperature above 30°C during the maturing stage of wheat causes force maturity and yield loss (Uddin et al., 2015). Early planting date showed the least possibility of high-temperature days during maturing phase of wheat. Moreover, the Mann-Kendall test values of the number of days with maximum temperature above 30°C during maturing stage for normal and late planting showed increasing trends (Table 4). The Mann-Kendall test values of the number of days with maximum temperature above 30°C during maturing stage for early planting did not show any increasing trend. Therefore, an earlier planting date could be the best option to avoid high-temperature stress during the maturing phase of wheat.

An estimate by Singh and Uttam (1999) indicates yield loss of wheat at 39 kg/ha per day for each day delay in sowing from optimum sowing date in India. Ahmed and Meisner (1998) reported that wheat yield in Bangladesh would decrease at the rate of 1.3% per day with a delay of sowing after 30 November under the short spell of winter. Different studies also indicated a significantly reduced in wheat yield under late seeding conditions due to lower dry matter accumulations in grain due to prevailing high temperature at grain filling period (Bhatta *et al.*, 1994; Tyagi *et al.*, 2003; Munjal *et al.*, 2004 and Hasina *et al.*, 2012). Therefore, a date between early and normal planting, i.e., between 20 October to 10 Novmber could be the optimum sowing date of wheat according to this study.

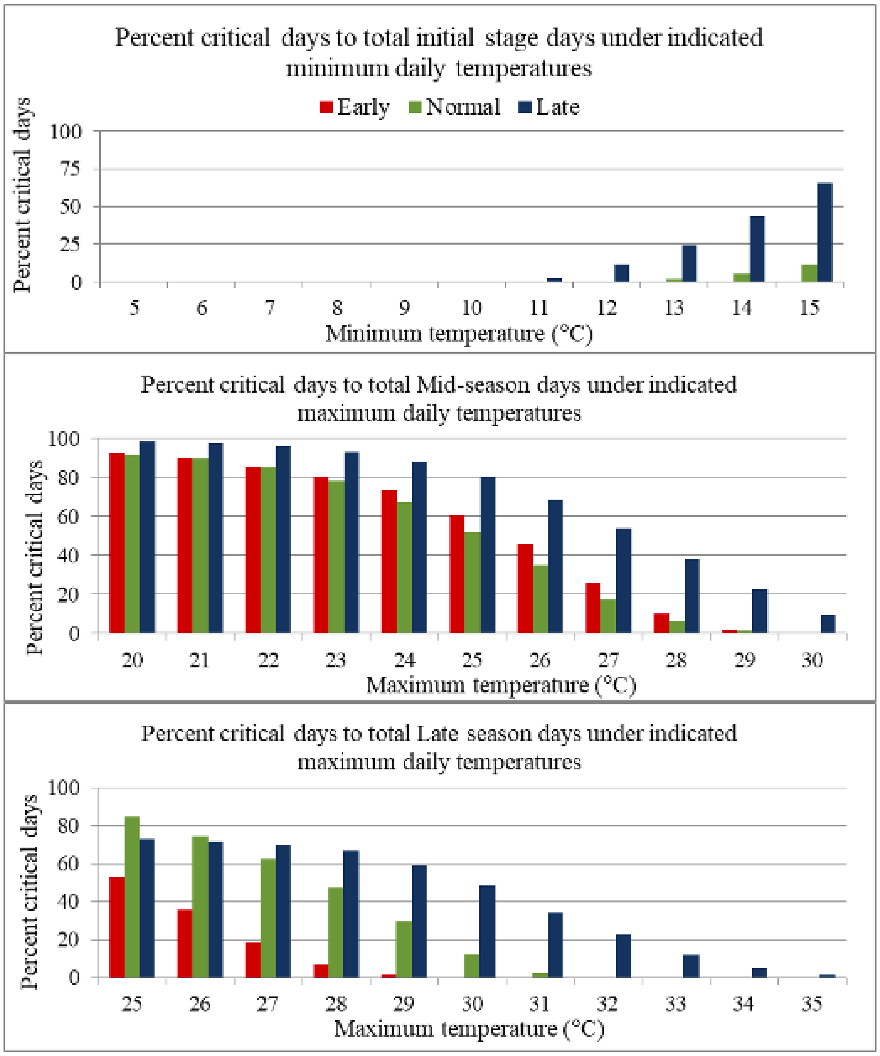

Figure 5. Percent cold stress days to total initial stage days and percent high-temperature stress days to total mid-season and late season days for wheat under early, normal and late planting in Bogura from 1980 to 2013.

Table 4. Mann-Kendall test values, i.e. Z-statistics and Sen's slope of estimated number of cold stress days, i.e. minimum temperature below 10 °C during initial stage and heat stress days, i.e. maximum temperature above 25 and 30 °C during reproductive and maturing stages of wheat in Bogura from 1980 to 2013

Planting time	Z-statistics of estimated number of cold/heat stress days			Sen's slope of estimated number of cold/heat stress days		
	Initial stage	Reproductive stage	Maturing stage	Initial stage	Reproductive stage	Maturing stage
Early planting	0	–0.52	0	0	–0.07	0
Normal planting	0	**–2.01***	0.26	0	–0.18	0
Late planting	0	0.04	1.22	0	0	0.08

* Sign indicate significant at 0.05 level of significance.

Conclusion

Estimated potential crop water requirement and irrigation requirement of wheat showed decreasing trends. This indicates that irrigated cultivation of wheat did not impose any additional pressure on available water resources in Northwest Bangladesh during last three decades. Although early planted wheat receives a reduced amount of effective rainfall during the growth period, still early planting option reduced irrigation requirement of wheat by a considerable amount than late planting because of reduction in potential crop water requirement. Early planting also showed no evidence of cold stress during the germination period of wheat. Furthermore, an earlier planting date would be the best option to avoid high-temperature stress during the maturing stage of wheat. However, selection of normal planting date would be the best option to avoid high-temperature stress during the reproductive phase of wheat.

Conflict of Interests

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

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