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Optimizing sowing window for wheat cultivation in Bangladesh using CERES-wheat crop simulation model

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ABSTRACT

Sowing date is a crucial factor for wheat (*Triticum estivum* L.) production. From traditional field experiments, optimum sowing date for wheat cultivation could be found out based on existing weather and soil conditions but not possible for futuristic sowing window to address climate change impacts. Crop simulation model can play an important role in this regards. So, a study was conducted at Regional Wheat Research Centre (RWRC), Bangladesh Agricultural Research Institute (BARI), Gazipur, Bangladesh to evaluate the CERES-wheat crop model in simulating optimum sowing window for wheat. Thirteen sowing dates starting from 21 October to 20 December at five days interval were tested with wheat cultivar BARI Gom-26. The model was calibrated and validated with one field experimental data followed by 30 years seasonal runs. Optimum sowing window for wheat is 15 November–30 November in Bangladesh. On an average, grain yield of wheat was reduced by 30–40 kg day^{-1} ha^{-1} when sown from 1 December to 20 December. Similarly, grain yield reduction was about 148–102 kg day^{-1} ha^{-1} with early sown wheat (21 October–14 November).

1. Introduction

Globally, wheat is the most important crop among cereals and covered about 225 million hectares (ha) during 2014–2015 and produced about 737 million tons grain (USDA, 2017). This production scenario is likely to be changed because of increase in Earth's surface temperature along with increasing water demand (Hassanein et al., 2012). Such situations will adversely affect the productivity of wheat in Bangladesh (Jahan et al., 2014). As a second most important cereal crop in Bangladesh, it covered 4.88 lakh ha and produced 13.55 lakh tons grain in 2015–2016 (WRC, 2016). Such area coverage and production might be changed in Bangladesh because of rise in mean temperature by 0.66 °C since 1999 and by 2.13 °C in 2050 (Poulton and Rawson, 2011). Besides, reduced wheat grain yields in Bangladesh are also the cause of inadequate rainfall and high temperature during grain filling stage at the end of growing season (Radmehr et al., 2003). Late seeded wheat crops are mostly exposed to heat stress that accelerate leaf senescence, reduce spikelet density, and cause spikelet abortion and thus results in lower yields (Al-Khatib and Paulsen, 1984; Pfeiffer et al., 2005; Radmehr et al., 2003).

In general, optimum sowing window is determined based on local field experiments that have been done periodically for a limited number of years and locations for a few varieties and final recommendations are extrapolated to other environments. However, the responses of grain yield of wheat to various sowing dates depend on seasonal weather variability across the years as well as locations. Therefore, extrapolating the results of a limited number of environments is not only difficult but may be misleading (Andarzian et al., 2007; Savin et al., 1995; Timsina

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et al., 2008). In this context, crop simulation models that have been evaluated with local experimental data could be valuable tools for extrapolating the experimental results to other years and other locations (Mathews et al., 2002).

Crop simulation models have been used to investigate the performance of different cultivars in a range of sowing dates under different soil and climate scenarios (Bannayan et al., 2013; Bassu et al., 2009; Heng et al., 2007; Pecetti and Hollington, 1997). The DSSAT is a comprehensive decision support system agro-technology tool (Hoogenboom et al., 2010; Tsuji et al., 1998) that includes more than 40 Cropping System Models (Ritchie et al., 1998; Ritchie and Otter, 1985) including CERES-Wheat model. The CERES-Wheat model can be used to simulate the growth and development of dry land and irrigated wheat across a range of latitudes (Hoogenboom et al., 2010; Nain and Kersebaum, 2007). This model has been evaluated and applied in a range of tropical (Timsina et al., 1995), sub-tropical (Heng et al., 2007) and temperate environments of Asia (Timsina and Humphreys, 2006; Zhang et al., 2013). Although CERES-Wheat model is a strong tool for assessing climate change impacts on wheat production, very much limited data are available for executing the program. This is more applicable for newly released wheat varieties in Bangladesh like BARI Gom-26, which covers about 36–40% area in Bangladesh.

Field experiments for finding out optimum sowing window of wheat, like BARI Gom-26, in different locations over the country are laborious as well as expensive. The CERES-Wheat model can easily and effectively handle such difficulties. Therefore, the simulation study was undertaken to find out optimum sowing window for wheat crop in Bangladesh and to find out yield reduction of wheat due to early and late sowing.

2. Materials and methods

2.1. Field study

2.1.1. Site description

The field study was located at Gazipur district in Bangladesh (23.45° N and 90.23° E and 8 m above mean sea level). The study area experiences a sub-tropical monsoon climate.

2.1.2. Soil properties

Experimental soils belongs to Grey Terrace Soil (Aeric Heplaquepts). Nutrient status of experimental soil is shown in Tables 1a & 1b.

2.1.3. Experimentation

One field experiment was conducted in 2013–2014 with six sowing dates and three nitrogen (N) levels. Sowing date was started from 1 November and continued upto 21 December at 10 days interval and N rates used were 40, 80 and 120 kg ha^{-1}. The treatments were laid out in Randomized Completely Block Design (RCBD) with three replications. Four cross ploughing by power tiller was given for land preparation. All stubbles of previous crop T. Aman rice were incorporated into the soil. Phosphorus (P), potassium (K), sulphur (S), zinc (Zn) and boron (B) were used 27, 60, 20, 5 and 1 kg ha^{-1}, respectively. Source of N, P, K, S, Zn and B were urea, triple super phosphate, muriate of potash, gypsum, zinc sulphate and boric acid, respectively. All P, K, S, Zn, B and 2/3rd N were applied during final land preparation and remaining 1/3rd N was top dressed at crown root initiation stage. Seeds were sown at 5 cm depth in continuous in line maintaining line to line distance 20 cm. About 30, 40 and 30 cm irrigation water were applied at crown root initiation, heading and initial grain filling stage. Weeding was done once by hand at 25–30 days after sowing. Fungicide Tilt 250 EC was applied @ 0.5 ml l^{-1} to control Bipolaris Leaf Blight (BpLB) of wheat. Other intercultural operations were done as and when necessary. Wheat crops of different plots were harvested at fully matured stage. Grain moisture was adjusted at 12% after sun drying of harvested grain. Grain yield and yield contributing characters were recorded and used for validation of DSSAT model.

Table 1a
Physical properties of Gazipur soil.

Soil layer (cm)	Sand (%)	Silt (%)	Clay (%)	Bulk density (Mg m^{-3})
0–15	30.84	46.42	22.74	1.52
15–30	20.84	47.35	31.81	1.53
30–60	20.48	40.24	39.28	1.56
60–90	23.48	43.71	32.81	1.57
90–120	19.84	42.35	37.81	1.61
120–150	18.84	45.21	35.95	1.63
150–180	19.36	46.28	34.36	1.66

2.2. Simulation study

The simulation study was conducted for Gazipur location using DSSAT v.4.6 model. The model was run using the weather and soil data of Gazipur. The soils of the study site were characterized as silty clay loam with moderate drainage.

2.2.1. Weather data

Generally warm and humid climate prevails at Gazipur. Weather data of Gazipur during wheat growing season are shown in Table 2.

2.2.2. Model description

DSSAT v.4.6 model (CERES-Wheat Crop Simulation Model) was used for the study. The model was run with six data sets: soil, weather, genetic coefficient, experimental file (X file), annual file (harvested data) (A file) and seasonal (time series data on leaf area index, dry matter partitioning data, etc) files (T file). Soil data included soil characteristics such as site latitude and longitude, soil type and soil series, pH, bulk density, soil texture and soil nutrient status like N and C content. Weather file included temperature (both maximum and minimum), humidity, solar radiation, rainfall etc. DSSAT model required some of crop management data like cultivar, sowing/planting date, line sowing/broadcast, plant spacing, nitrogen levels, tillage practices and organic amendments (Jones et al., 2003) in experimental file (X file) to simulate crop productivity. Phenological data like different stages of crop growth such as days to heading, days to anthesis (flowering), days to physiological maturity, days to harvest, yield contributing parameters, grain yield and biological yield were also recorded. In order to simulate yields under different sowing dates, the CERES-Wheat model was calibrated and validated initially. Climatic data were collected from the weather station of Gazipur under the Department of Metrology, Peoples Republic of Bangladesh. The input files, such as weather file, soil file, A file, T file (leaf area index, dry matter partitioning data, etc) were prepared for applying in the CERES-Wheat model to predict wheat yields under different sowing dates.

2.2.3. Optimum window for sowing dates of wheat

Optimum window for sowing dates of wheat was based on genetic co-efficient of wheat cultivar BARI Gom-26, soil file, weather file and seasonal file. One experiment was simulated having 13 sowing dates starting from 21 October to 20 December at 5 days intervals on BARI Gom-26 to find out optimum sowing window for wheat cultivation in Bangladesh.

2.2.4. Model application

DSSAT v.4.6 model (CERES-Wheat Crop Simulation Model) was run (seasonal run) for 30 years from 1980 to 2010. Predicted wheat yields were generated using this seasonal run. Scenarios (30 years data) were developed to assess the sensitivity of the crop to different sowing dates for adjusting/minimizing the grain yield reduction of wheat for Bangladesh. These scenarios were implemented in the DSSAT model, and the outputs were analysed using graphical techniques to compare