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Predicting the impact of climate change on water requirement of wheat in the semi-arid Indo-Gangetic Plains of India

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ABSTRACT

Crop water requirement (CWR) under the projected climate change could be mediated through changes in other weather parameters including the air temperature. The present study was directed to assess the on-farm water requirement in wheat crop in future, in semi-arid Indo-Gangetic Plains of India, through field and computer simulations. Field simulation using temperature gradient tunnels shows 18% higher crop evapotranspiration (ET_c) and 17% increase in root water extraction at 3.6 °C elevated temperature compared to 1.5 °C increase over the ambient. A time series model (ARIMA) with long-term (1984–2010) weather data of the experimental site and a global climate model (IPCC-SRES HADCM3) were used to simulate the potential ET (ET_0) of wheat for 2020–2021 and 2050–2051 years. The crop coefficient (K_c) values for these years were generated through K_c–CGDD (Cumulative growing-degree-days) relation by using LARS-WG model-derived daily minimum and maximum temperatures. The CWR and NIR (Net Irrigation Requirement) are likely to be less in projected years even though air temperatures increase. The CWR reduces in ARIMA outputs owing to a lower reference ET (ET_0) due to decline in solar radiation. Under IPCC-SRES scenarios, the ET_c–crop phenophase relation [CGDD–LGP (length of growing period) response] may offset the effect of rising temperature and a net decline in CWR is observed. It may be likely that the effect of temperature increase on CWR is manifested mostly through its relation with crop phenophase (thermal requirement to complete a specific growth stage) and not the temperature effect on ET_0 per se. This is certainly a ray of hope in managing the depleting irrigation water resources in the semi-arid wheat-growing regions of the IGP.

1. Introduction

Global climate change continues to be a major concern in the present century, and atmospheric temperature is the major indicator of the change on both global and regional scales. A rise in temperature may bring an adverse effect on the availability of water. Agriculture is the largest sector in water use in many countries including India. The impact of climate change on crop evapotranspiration therefore becomes important for water management and agricultural sustainability (Mo et al., 2013). The warmer climate may increase the ET_0 of crops leading to greater demand for irrigation water. Climatic factors other than temperature, like radiation, humidity, wind speed and rainfall also influence the ET_0. Consequently, any variation in these factors will also modify the ET_c. These changes are however, difficult to project especially on regional (Chattopadhyay and Hulme, 1997) or local scales. Downscaling techniques including use of weather generators (Wilks, 1992) can be effective. Climate change studies have been conducted in India on a general scale (e.g., Thapliyal and Kulshrestha, 1991; Rupakumar et al., 1994; Rao et al., 1996; Piao et al., 2010; Pandeya and Mulligan, 2013; Zhang and Cai, 2013), or specifically on ET_0 (Chattopadhyay and Hulme, 1997), but only a few studies (e.g., Goyal, 2004) have assessed the impact of local weather trend and climate change scenarios on crop water requirement.

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Wheat is a thermo-sensitive crop, and change in air temperature may alter the length of its growing period. Water requirement is specific to its phenological stage and hence, a small shift in even a single growth period will modify its stage-specific and seasonal water demands at the farm-scale. Evaluating stage-variable water requirement in wheat under future climate change can improve our preparedness to meet the irrigation demand in future, although studies in this direction are lacking (Doria et al., 2006). While IPCC climate scenarios can help in understanding these variations at the farm-scale, historical trend analysis of local weather parameters will also serve as an important tool to this effect.

In the present study, we made an attempt to evaluate the effect of changing climate on the on-farm water requirement in wheat in a semi-arid region of the Indo-Gangetic plains of India. A two-pronged approach was followed, involving field study (using temperature gradient tunnels) and computer simulations (using local weather trends and IPCC climate scenarios).

2. Material and methods

2.1. Field study: temperature gradient tunnel (TGT) experiment

Wheat (*Triticum aestivum* L.) was grown during 2009–2010 and 2010–2011 in temperature gradient tunnels (TGT; 10 m × 2.5 m × 2.5 m) made of transparent plastics. Fans were fitted at front and back side of the tunnel for regulations of temperature. During day, fresh air was introduced to the tunnel by monitoring the fan speed between 20% of full output and maximum speed, and the temperature gradient was maintained from one end to the other. Inside the tunnel, 4 sensors were fixed to continuously monitor the temperature by every 15 min. For experimental purpose, we considered two temperature segments, at 3.6 °C (greater-elevated, T_G) and 1.5 °C (lesser-elevated, T_L) higher above the ambient (open atmosphere) temperature. A total of 12 rows of crop were sown on 26th November (both the years) in north-south directions with row-to-row spacing of 26 cm. Plants were adequately irrigated, and standard agronomic and crop protection practices were followed to keep the crop healthy and disease free.

Soil water contents were monitored using neutron moisture probe and the crop ET was calculated as described in Chattaraj (2012).

2.2. Local weather trend analysis and climate scenario generation

Daily minimum and maximum temperatures (T_{MAX} and T_{MIN}, °C), relative humidity (RH, %), bright sunshine hours (BSH, h) and wind speed at 2 m height (WS, km day^{-1}) of the IARI farm during 1984–2010 were analyzed using ARIMA (Auto Regressive Integrated Moving Average) time series model (Box et al., 1994) to generate scenarios for the years 2020–2021 and 2050–2051. We used data pertaining to wheat season (November to April) only. The best model was selected based on minimum AIC (Akaike Information Criteria) and BIC (Bayesian Information Criteria) values, while the forecasting ability of the model was judged by mean absolute percent error (MAPE) and efficiency (E). Data for the years 2009 and 2010 were used for validation.

The reference evapotranspiration (ET_0) was calculated using FAO Penman–Monteith (P–M) equation (Allen et al., 1998), and regressed against T_{MAX},T_{MIN}, RH, WS and BSH.

2.3. IPCC scenarios for 2020–2021 and 2050–2051

The climate change scenarios of IPCC-TAR (2001) were generated using HADCM3 global climate model. Mean monthly anomalies of T_{MAX} and T_{MIN}, RH, WS, BSH and precipitation for the periods, 2010–2039 and 2046–2065 with respect to baseline, 1961–1990, were used to generate scenarios (A1F, B1a, A2a and B2a) for 2020–21 and 2050–51. The data sets were obtained from open-source IPCC Data Distribution Centre (www.ipcc-data.org).

2.4. Conversion of monthly mean T_{MAX} and T_{MIN} to daily values

Monthly anomalies of T_{MIN} and T_{MAX} obtained from IPCC-SRES were fed to the LARS-WG weather generator (Semenov, 2007) to convert to daily values based on the statistical distribution of observed long-term (1984–2010) daily weather data. This was done to compute the cumulative growing-degree-days (CGDD), which was further used to simulate the potential K_c by using field-derived K_c–CGDD relations (Chattaraj et al., 2013). No adjustments were made for daily T_{MIN} and T_{MAX} variability, which would require daily output from the GCMs, and were not readily available from the IPCC Data Centre. Similar procedure was followed to get daily T_{MIN} and T_{MAX} data in ARIMA model-generated scenarios.

2.5. Computation of crop water requirement (CWR) and net irrigation requirement (NIR)

The ET_0 was calculated from daily weather parameters by using P–M equation. The monthly mean ET_0 for the future were obtained by forcing the deviations (scenarios-generated) to the long-term average. The K_c–CGDD relation was developed and validated by using field experimental data. Daily temperature output from LARS-WG model was used to calculate the CGDDs for 2020–2021 and 2050–2051. Daily ET_c was calculated by multiplying K_c with ET_0 and integrated over the season to obtain the crop water requirement (CWR). In IPCC scenarios, crop duration varied according to CGDD (CGDD for the growing season under present scenario was 1738.5 °C-day, the average of 2009–2010 and 2010–2011).

Following the CROPWAT approach (Smith, 1992), the NIR (mm) for the growing season was computed as the difference between the CWR and the effective seasonal rainfall (P_{eff}), which is the fraction of total precipitation (P) available to the crop, and does not run off. We used a simple approximation following the USDA Soil Conservation Method (Smith, 1992) to determine P_{eff} as:

$$P_{eff} = \frac{P(4.17 - 0.2\,P)}{4.17}, \text{ for } P < 8.3 \text{ mm day}^{-1}$$

$$P_{eff} = 4.17 + 0.1\,P, \text{ for } P \geq 8.3 \text{ mm day}^{-1}$$

CROPWAT used the monthly rainfall data for the future scenarios as discussed earlier in the text for other weather parameters. The overall methodology adopted for the study is presented in Fig. 1.

3. Results

3.1. Temperature gradient tunnel experiments

Higher temperature forced an early maturity of the crop. Duration of growth stages was short in T_G compared to that in T_L (Fig. 2). The ET_c was nearly similar at CRI (1.8 and 2.0 mm in T_L and T_G with 24 and 20 days duration, respectively). The tillering period was 7 days less in T_G, resulting in 65% lower ET_c compared to that in T_L. During jointing, ET_c was 19% higher in T_L due to extended 4 days. During flowering, the difference reduced (9% higher ET_c under T_L), although the duration was shorter by 10 days in T_G. The milking stage was reduced by 3 days under T_G but the ET_c was 30% higher. At dough stage, ET_c was 9% higher in T_G, whereas duration was 2 days short. The crops matured 11 days early and the ET_c was 37% higher under T_G. The seasonal ET_c was 259.2 mm in T_G, which was 7.6% higher than in T_L.