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Adaptation strategies to lessen negative impact of climate change on grain maize under hot climatic conditions: A model-based assessment

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ABSTRACT

Rise in temperature, particularly in warmer areas, could have a negative effect on maize productivity. However, careful management practices could reduce the effects of high temperatures by altering the sowing dates and type of cultivar. The current study applied APSIM (The Agricultural Production Systems sIMulator) crop model to investigate the interaction of sowing date and cultivar when dealing with climate change and high temperatures at nine locations in Khuzestan province, in southwestern Iran. Daily climatic data for the baseline period of 1980–2010 was obtained from the Meteorological Organization of Iran. Projections of the future climate of Khuzestan was done in Miroc5 (Model for Interdisciplinary Research on Climate) GCM (Global Climate Model) for 2040–2070 under two RCPs (Representative Concentration Pathways) (RCP4.5 and RCP8.5) using the methodology developed by AgMIP (The Agricultural Model Intercomparison and Improvement Project). The high risk window for extreme temperature was calculated as the number of days having a maximum temperature of over 36 °C (Tmax > 36 °C) during pre-flowering and flowering. Results indicated that for mid-future (2050), the average maize grain yield in almost all study areas except Masjed Soleyman decreased in comparison to baseline at −13.7% and −22.8% for RCP4.5 and RCP8.5, respectively mainly because the length of the high-risk window for extreme temperature had expanded from 18.8 to 26.3 days for RCP4.5 and RCP8.5, respectively, compared to baseline. Most farmers have not realized that they are currently sowing maize during a high-risk window for extreme temperatures (Tmax > 36 °C) in some seasons. If farmers do not apply adaptive options for their regions (most promising sowing date × cultivar), the probability of economical grain yield will be less than 50% for an average economical grain yield of 8.9 t ha^{-1}. The current findings support the hypothesis that climate change by the middle of the 21st century will not be beneficial for maize agroecosystems in hot areas like Khuzestan province unless the best sowing date × cultivar is applied for both winter and summer sowing dates.

1. Introduction

Khuzestan province in southwestern Iran (Fig. 1) features a hot climate. With 8.85% of the total area under cultivation in Iran, it is the largest producer of the crops in the country. The province produces 78,318 ha of maize (33.5% of cultivated area) equaling about 29.7% of the maize production in Iran (Anonymous, 2014a), but the average grain yield for a farm (5 t ha^{-1}) does not meet the highest potential yield (Agricultural Jihad Organization of Khuzestan Province, 2016; personal communication).

Over the past three decades, the mean temperature of Khuzestan province has risen about 1.96 °C (Dashtbozorgi et al., 2015). The rise in temperature, particularly in warmer areas, could have a negative effect on maize productivity by decreasing the length of the growing season (Liu et al., 2010; Olesen, 2005; Porter, 2005; Tubiello et al., 2000), pollen viability and seed set (Dupuis and Dumas, 1990; Hatfield and Prueger, 2015; Herrero and Johnson, 1980; Lobell et al., 2015; Singh et al., 2015, 2016).

Careful management practices could reduce the exposure of the flowering stage to high temperatures by altering the sowing dates and type of cultivar. Farmers in Khuzestan province usually sow maize in the winter and summer with flowering stages occurring between 30 April and 23 May and 21 September and 6 October, respectively. Experts around the world have generally reported that early sowing dates for winter cultivation and late sowing for summer cultivation can be considered to avoid heat stress (Liu et al., 2013; Zheng et al., 2012).

The use of a cultivar having a different maturation schedule could also limit the impact of heat stress. The flowering stage of the cultivar depends on the time of leaf appearance, photoperiod sensitivity and other cultivar-specific parameters (Kumudini et al., 2014). To decrease the risk of heat stress under climate change, the effects of the interaction of cultivar, season and sowing date (G × E × M) should be

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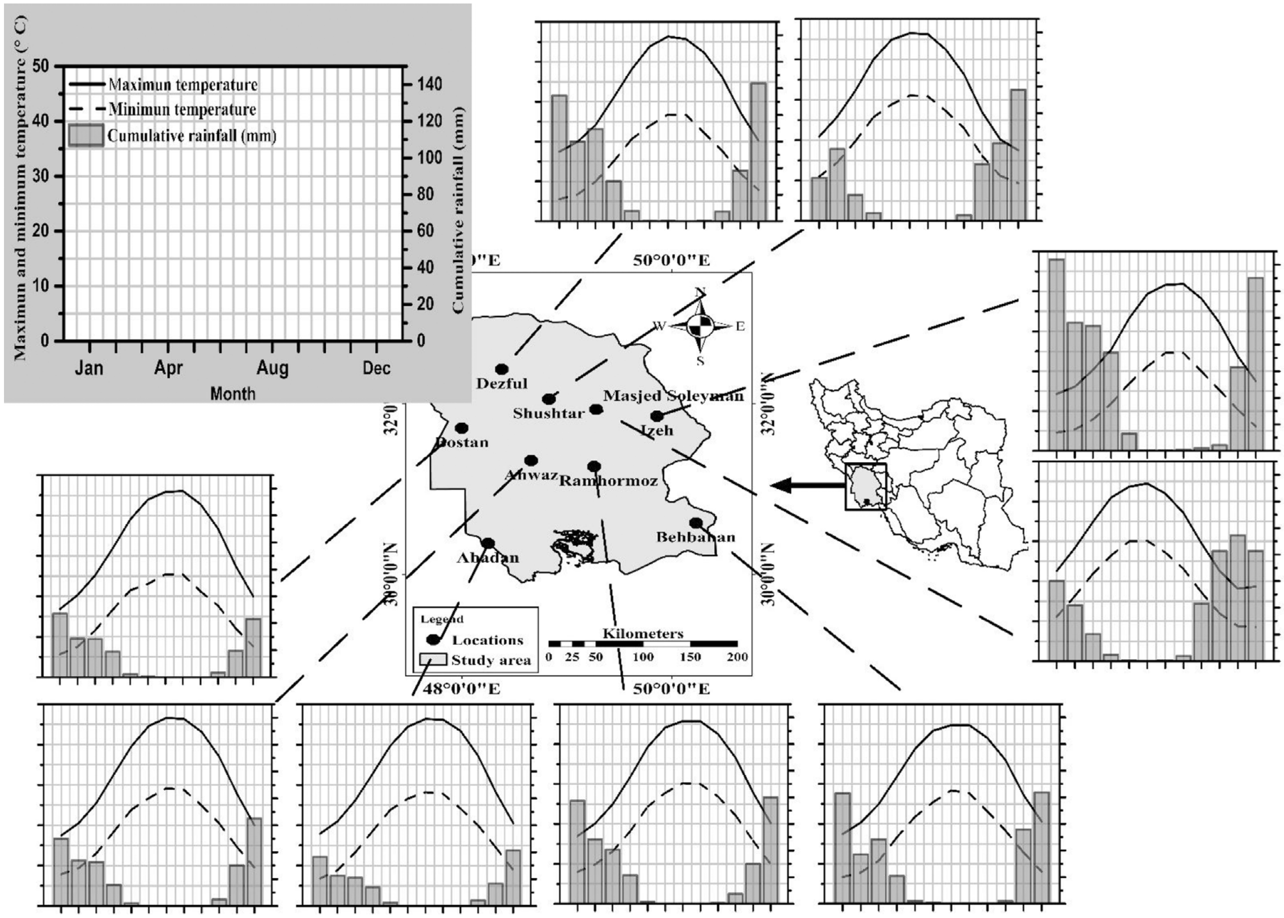

Fig. 1. Geographical details and long-term monthly cumulative rainfall (columns) and maximum (solid line) and minimum (dash line) temperatures of meteorological stations at study locations averaged from 1980 to 2010. Scales are given in this shaded box at the top-left of the figure.

considered.

Liu et al. (2013) reported that early sowing dates combined with cultivars having higher thermal time requirements lessened the negative impact of global warming on maize grain yield in northeastern China. Alexandrov and Hoogenboom (2000) studied the impact of climate variability and changes on crop yield in Bulgaria and found that adaptation strategies such as changes in sowing date and hybrid selection could potentially reduce the impact of climate change on maize production. Moradi et al. (2013) reported the positive effects of early sowing date on maize yield under climate change conditions in northeastern Iran.

Simulation models can be used to evaluate environmental impact of climate change (Chenu, 2015; Chenu et al., 2013; Zheng et al., 2012). Feasible roles of crop simulation models include assessing the effect of agricultural management practices on crop productivity (Amiri et al., 2016; Brisson et al., 2003; Deihimfard et al., 2015; Jones et al., 2003) and of climate change on crop yield (Asseng et al., 2011; Lobell et al., 2015; Zheng et al., 2012). These have been shown to be suitable for assessing the effects of climate change on crop yield (Asseng et al., 2011; Liu et al., 2012; Zheng et al., 2012), the effect of sowing date and cultivar (Liu et al., 2013; Zheng et al., 2012) and of high temperatures (Lobell et al., 2015). APSIM model is one of the crop simulation models that has the ability to accurately simulate the management effects on crops (e.g. Deihimfard et al., 2015) and the effects of extreme temperatures on maize growth, pollen viability and seed set (e.g. Lobell et al., 2015, 2013). In addition, this model has been evaluated for many crops (such as wheat and maize) and cultivars under Iranian climatic and management conditions with high accuracy (e.g. Deihimfard et al., 2015; Soltani and Sinclair, 2015; Abbaspour et al., 2014).

The current study applied Agricultural Production Systems sIMulator (APSIM crop model) to investigate the interaction of sowing date and cultivar when dealing with climate change and high temperatures. The objectives of the current study were (i) to assess the effects of climate change and high temperatures on the maize yield in Khuzestan province, (ii) to determine the high-risk windows for heat stress during the flowering stage in each region of Khuzestan province and (iii) to evaluate the role of adaptation strategies (sowing date and cultivar) to lessen the negative impact of climate change on maize productivity under the hot climatic conditions of Khuzestan province.

2. Materials and methods

2.1. Study locations

The current study was conducted in Khuzestan province, located in the sub-humid agro-climatic zone of southwestern Iran (Fig. 1). The study focused on nine locations in Khuzestan province: Abadan, Ahwaz, Behbahan, Bostan, Dezful, Izeh, Masjed Soleyman, Ramhormoz and Shushtar (Fig. 1). The criteria for selection these locations were the size of the area under maize cultivation, climatic diversity and province-wide distribution.

2.2. Weather data and climate scenarios

Daily climatic data for the baseline period of 1980–2010 was obtained from the Meteorological Organization of Iran. The climatic data contained the duration of sunlight (h), maximum and minimum air temperature (°C) and precipitation (mm). As the daily solar radiation