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Towards shifting planting date as an adaptation practice for rainfed wheat response to climate change

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ABSTRACT

Maintaining rainfed crop production particularly in water-limited environments is of great importance for agricultural water management under climate change (CC). In such conditions, there is a real demand for finding some practical adaptation scenarios to sustain optimal crop production. This study aimed to investigate the impacts of CC on rainfed wheat yield, transpiration to total evapotranspiration ratio (T/ET) and maximum leaf area index (LAIm) in some semi-arid areas in Iran over 2071–2100 under the current and shifted planting date scenarios. Consequently, the outputs of five climate models under RCP-4.5 and RCP-8.5 emission scenarios downscaled by MarkSimGCM were used to run the CSM-CERES-Wheat v4.6 model. Results revealed that crop yield, T/ET and LAIm will decrease chiefly due to October–November–December (OND) and January–February–March (JFM) precipitation deficit under current sowing date at the most studied sites. Unlike early planting, postponing sowing date from the current to the best date as an adaptive alternative will increase the received precipitation during two early growth phases i.e. germination to terminal spikelet initiation (G-TS) and terminal spikelet to end of leaf growth and beginning of ear growth (TS-ELG). However, a considerable change in the precipitation of entire growing season and grain filling (GF) stage due to delay in sowing date was not projected. Enhanced G-TS rainfall will ensure crop emergence and establishment. Moreover, precipitation increase at TS-ELG phase in which the highest decrease of precipitation was predicted, would enhance LAIm and T/ET. This can be attributed to the fact that the vapor flux in the soil–plant–atmosphere system may shift in favor of transpiration loss through delaying planting date. Therefore, by better matching crop development with changed rainfall distribution, postponing sowing date can partially compensate the deleterious impacts of CC-induced drought on rainfed wheat yield in the west and northwest Iran during 2071–2100.

1. Introduction

Agricultural water management for crop production and food security in water-limited systems is largely influenced by water scarcity and non-water limiting factors such as poor nutrition and salinity (Rockström et al., 2010; Saadat and Homaee, 2015). In arid and semi arid regions, water scarcity (Homaee et al., 2002a,d) and salinity (Homaee et al., 2002b,c; Homaee and Schmidhalter, 2008) are two main important challenges for agricultural water management. Since pre-industrial period, rising atmospheric concentration of greenhouse gases and aerosols mainly due to fossil fuel overuse, land use/cover changes and agricultural activities have triggered anthropogenic global warming and climate change (CC) (IPCC, 2013). Drought exhibited upward trend since 1950 and was projected to be more severe and widespread in the future owing to CC (Dai, 2011, 2013). In the eastern Middle East including the western Iran, meteorological drought would also be more frequent and severe due to declined storm track activity (Evans, 2009). In other words, the already drought prone regions such as Iran are likely to be more liable to CC-related drought (Li et al., 2009).

Being highly vulnerable to meteorological drought, rainfed agriculture is anticipated to be highly impacted by climatic changes particularly in arid and semi-arid regions (Falkenmark, 2013). Producing wheat (*Triticum aestivum L.*), as a primary staple food of billions of people, seems to be highly susceptible to the future CC under rainfed condition in water-limited regions (Anwar et al., 2007; Eyshi Rezaie and Bannayan, 2012; Fischer et al., 2002). Considering increasing trend of environmental and industrial water

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allocation (Faures et al., 2007; Molle et al., 2007), recurrent water stress due to surface and groundwater depletion and projected rainfall deficit, substantial expansion of irrigated lands may not be feasible in the future (Rockström et al., 2010). On the other hand, more agricultural production is needed to guarantee food security of rising population. As a result, management of green water storage (i.e. soil moisture) under rainfed agriculture instead of direct using of blue water (or irrigation) appears to be of high importance not only to achieve food security in a sustainable way, but also not to increase water demand under CC (Rockström et al., 2009; Rockström et al., 2010). In addition, there is a great potential of bridging yield gap (between achieved and potential yield) under rainfed condition through field water management particularly in developing countries (Rockström et al., 2007). Hence, rainfed agriculture will keep playing an important role in meeting food security and coping with CC-induced water shortage (Rockström et al., 2007; Rockström et al., 2010).

Given the importance of rainfed agriculture under future CC and projected rainfed wheat yield loss, adapting wheat cropping system to a drier and warmer climatic condition seems to be a key measure in water-limited areas. It is worth mentioning that adopting adaptation strategies will be more required for the late 21st century in which climatic changes are expected to be stronger (IPCC, 2013). Since the main limiting factor in dryland agriculture is water deficiency, adaptive policies should mainly focus on improving yield through promoting water use efficiency (WUE) rather than using more water (Rockström et al., 2010; Stewart and Steiner, 1990; Yang et al., 2015). At the farm level, manipulating cropping calendar by changing sowing date is one of the adaptive options to alleviate negative impacts of CC on yield (Turral et al., 2011). Better soil water condition at early growing season provided through adjusting planting date improves crop WUE and yield (Turral et al., 2011). Moreover, change in sowing date can shift vapor flux from evaporation (non-productive water loss) to transpiration (productive water loss) in the soil–plant–atmosphere system and enhance green water use efficiency (Rockström, 2003). In other words, CC-induced dry spells can be bridged by shifting planting date (green water management) without using anymore blue water. This would be much more valuable in those courtiers such as Iran which already faced water scarcity and have some potential for enhancing WUE by vapor shift (Rockström et al., 2009).

Hitherto, some studies have been carried out to assess the impacts of shifting sowing date on wheat yield under changing climates (Delécolle et al., 1995; Ghahramani et al., 2015; Rosenzweig, 1990; Southworth et al., 2002; Torriani et al., 2007; Tubiello et al., 2002). The results of these studies indicate that shifting planting date is a region-specific adaptation. The climatic condition may also influence the effectiveness of manipulating sowing date. Weiss et al. (2003) investigated effects of delaying planting date on winter wheat production in two semi-arid and one sub-humid sites located in Nebraska. They concluded that yield loss would decrease in semi-arid and increase in sub-humid areas due to late planting. Delécolle et al. (1995) also pointed out that the effectiveness of changing sowing date highly depends on applied general climate model (GCM) and emission scenario. The effectiveness of adjusting sowing date as an adaptation alternative may, therefore, vary in different regions and also when different GCMs and emission pathways are used. The strategy of shifting planting date should thus be tested for each specific region using an ensemble average of multiple GCMs to reduce projection uncertainty.

This study was aimed (i) to find climate change impacts on rainfed wheat yield, maximum leaf area index (LAIm) and transpiration to evapotranspiration ratio (T/ET) during the 2080s (2071–2100) in the west and northwest of Iran and (ii) to evaluate the influence of shifting sowing date as an adaptation measure on wheat grain yield, T/ET, LAIm and precipitation quantity at five different wheat phenological stages.

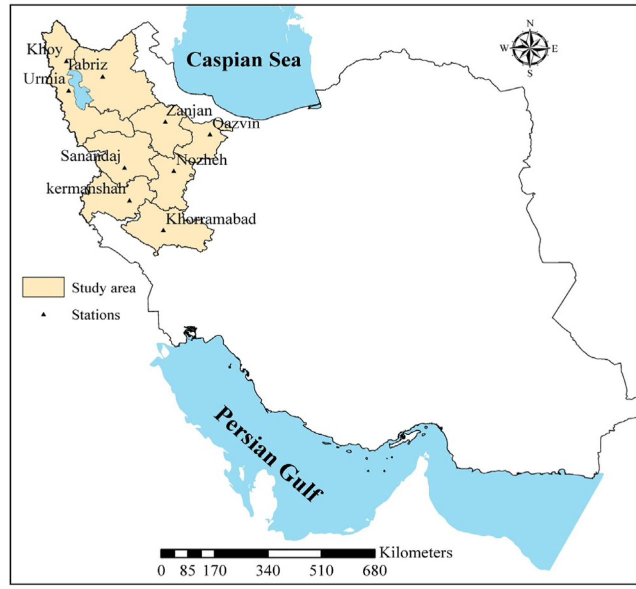

Fig. 1. The study areas located in the west and northwest of Iran.

2. Materials and methods

2.1. Study area

Iran has a wide range of climatic conditions mainly due to existence of the Alborz and the Zagros mountain ranges. Rain producing air masses predominantly enter from the west and northwest of the country causing above-average rainfall (300–500 mm annual precipitation) in the western half of the country owing to the Zagros mountain chain geographical location. Consequently, a semi-arid climate mostly dominates in the west and northwest of Iran. The local map of the study area is depicted in Fig. 1. The climate of all studied sites is categorized as semi-arid according to UNEP (1997). Semi-arid climatic condition as well as fertile plains have made the western half of Iran an appropriate area for rainfed agriculture. Around 75% of all rainfed wheat produced in Iran is harvested from the fields located in the studied regions (Ministry of Agriculture, 2011). Annual average rainfed wheat yield in the studied area is approximately 900 kg ha^{-1}.

2.2. Data

2.2.1. Climatic data

In this study, MarkSimGCM was employed to downscale coarse-scale GCMs (General Circulation Models) outputs to a $0.5^{\circ} \times 0.5^{\circ}$ latitude/longitude grid resolution using stochastic downscaling and climate typing techniques (Jones and Thornton, 2013). MarkSimGCM generates rainfall data based on third-Markov stochastic model and daily temperature (minimum and maximum) as well as solar radiation data using Richardson (1981) approach. Further, MarkSimGCM collects the baseline period climate data (1961–1990) from the WorldClim database. The model has been employed to downscale GCMs outputs in different climates over the globe (Fouial et al., 2016; Liu et al., 2016; Mathukumalli et al., 2016; Nouri et al., 2016; Shirsath et al., 2017). Nouri et al. (2016) showed that MarkSimGCM can successfully produce the required climate data for agrohydrological modeling over Iran. For our assessment, an ensemble mean of five GCMs participating in the fifth phase of Coupled Model Intercompar-