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Research paper

Quantification the impacts of climate change and crop management on phenology of maize-based cropping system in Punjab, Pakistan

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ABSTRACT

Crop production is greatly impacted by growing season duration, which is driven by prevailing environmental conditions (mainly temperature) and agronomic management practices (particularly changes in cultivars and shifts in sowing dates). It is imperative to evaluate the impact of climate change and crop husbandry practices on phenology to devise future management strategies to prepare for climate change. Historical changes in spring and autumn maize phenology were observed in Punjab, Pakistan during 1980–2014. Sowing (S) of spring maize was earlier by an average of 4.6 days decade^{-1}, while autumn maize 'S' and emergence (E) were delayed on average 3.0and 1.9 days decade^{-1}. Observed anthesis (A) plus maturity (M) dates were earlier by 7.1 and 9.2 days decade^{-1} and 2.8 and 4.4 days decade^{-1}for spring and autumn maize, respectively. Similarly, S-A, S-M and A-Mphases were shortened on average by 2.4, 4.6 and 1.9 days decade^{-1} and 5.5, 7.8 and 2.2 days decade^{-1} for spring and autumn maize, respectively. The variability in phenological phases of spring and autumn maize had significant correlation,with the increase in temperature during 1980–2014. Employing the CSM-CERES-Maize model using standard hybrid for all locations and years illustrated that model-predicted phenology has accelerated with climate change more than infield-observed phenology. These findings suggest that earlier late sowing and shifts of cultivars requiring high total growing degree day during 1980–2014, have partially mitigated the negative impact of climate change on phenology of both spring and autumn grown maize.

1. Introduction

Punjab is the most populated (99.94 million) province, with 57% of total population of Pakistan and it is the second largest province area-wise (205344 square kilometer) after Baluchistan (GOP, 2015). The prevailing climate of central Punjab is semiarid (mean temperature 10.5–24.4 °C and rainfall 300–600 mm) and southern Punjab is arid (mean temperature 18.5–31.4 °C and rainfall 75–200 mm). Mostly precipitation occurs during monsoon season (July-September) in central and southern Punjab (Nasim et al., 2012; Rasul et al., 2012; Ahmad et al., 2016; Mehmood et al., 2016).

Maize is the third largest cereal/grain crop area-wise and produces raw material for an array of multiple products in Pakistan. Its share in value added agriculture (VAA) and gross domestic product (GDP) is 2.1% and 0.4%, respectively in Pakistan. The area used for crop production and annual total production in Punjab province and Pakistan (GOP, 2015) is presented Fig. 1.

Climate change will significantly impact agricultural production in recent and coming decades, based on research studies conducted at local, regional, continental and global levels (Rasul et al., 2012; Estrella et al., 2007; Lobell et al., 2013; He et al., 2015; Ahmad et al., 2016, 2017a; Amin et al., 2017a; Fahad and Bano, 2012; Fahad et al., 2013,

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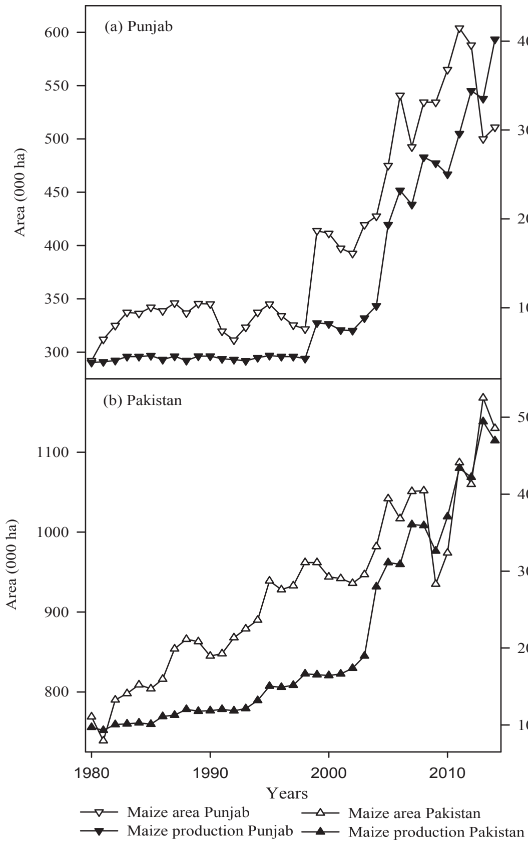

Fig. 1. Maize area and production from 1980 to 2014 forPunjab (a) and Pakistan (b), respectively.

2014a, 2014b, 2015a, 2015b; Noman et al., 2017; Saud et al., 2013, 2014, 2016, 2017). The mean surface air temperature of the earth has increased by 0.8 °C from the industrial revolution to recent years (IPCC, 2014). It has been reported that the warmest decade throughout the past decades was the 2000 s and the most recent warmest year was 2014 (IPCC, 2014). A climate change trend has also been reported for Punjab, Pakistan throughout the previous three decades and predominantly in 2000 s (Wang et al., 2011a; Amin et al., 2015; Nasim et al., 2016a, 2016b). The mean annual surface temperature has increased consistently, which affects the socio-economic sector of Pakistan (Farooqi et al., 2005; Akram and Hamid, 2015; Ahmad et al., 2015; Abbas et al., 2017; Adeel et al., 2017). The observed average warming trend in central and southern Punjab, Pakistan has ranged from 0.80 to 1.4 °C during the past three decades and could increase 2–4 °C in the future, which could be a very serious threat to the agricultural sector (Afzaal et al., 2009; Rasul et al., 2012; Mueller et al., 2014; Anjum et al., 2016; Ali et al., 2016; Ahmad et al., 2017a, 2017b).

Crop phenology (stages and phases) is driven by the prevailing weather conditions and normally expressed in growing degree day's accumulation. It affects crop management practices including cultivar selection and shifts in sowing dates (Tubiello et al., 2002; Menzelet al., 2006; Kucharik and Serbin, 2008; Lashkari et al., 2012; Lin et al., 2015; Ahmad et al., 2016; Ishaq and Memon, 2016; Jan et al., 2017). The negative impact of climate change especially due to an increase in temperature on crop phenology can be mitigated by changes in crop management. For example, developing and introducing new cultivars with a longer duration of the growth period could have a positive impact on crop phenology and ultimately enhance yield under a warming trend (Araya et al., 2015; Amin et al., 2016; Amin et al., 2017b; Fahad et al., 2016a, 2016b, 2016c, 2016d). An increase in temperature during the growing season due to climate warming has a negative impact of maize phenology, including the individual growth stage and phase duration. Variations in phenological stages and phases of a crop are vital indicators of changes in environmental situations and climatic conditions (Streck et al., 2008; Li et al., 2014; Meng et al., 2014; He et al., 2015). Climate thermal trend could accelerate the phenological stages of crop, while longer duration cultivars could cause slower development (Moradi et al., 2013; Javaid et al., 2017). Interactions among cultivar shifts, crop management practices and environmental change, however, cannot be analyzed and interpreted with statistical models. Crop growth models can efficiently simulate the relationships among changes in local weather conditions, cultivar change and crop management practices. However, the impact of multiple and interacting factor on crop phenology can be separated into single factor impact (Liu et al., 2012; Wang et al., 2013; Zhao et al., 2014; Khan et al., 2016; Qasim et al., 2016; Rozina et al., 2017). Xiao et al. (2016) reported that changing cultivar delayed physiological maturity and resulted in longer reproductive phase by 2.4–3.7 days decade^{-1} in North China Plain. Maize anthesis **(A)** and physiological maturity **(M)** were delayed and total growth duration was also prolonged by an average 1.5, 6.5 and 6.3 days decade^{-1}, respectively, in North China region. Therefore, there is a need to conduct research on the potential application of management practices and their adaptation for developing new strategies to mitigate the negative impacts of climate change on crop phenology (Gouache et al., 2012; Zhang and Huang, 2013; Lakho et al., 2017).

The purpose of this research was to evaluate the phenological trends of spring and autumn maize crop through 1980–2014 based on observed data collected from 10 locations for central and southern Punjab, Pakistan. One of the objectives was to correlate farmer field-observed phenological stages and phases with trends of increasing temperature to determine the extent to whichthe warming trends have had an impact on phenology of spring and autumn maize crops. The second objective was to use a dynamic crop simulation model to study the individual impacts of the warming trend, crop husbandry practices and hybrid shifts on spring and autumn maize phenology in central and southern Punjab, Pakistan.

Table 1
Spring and autumn maize hybrids grown at different location in Punjab*, Pakistan.

Sr. No.	Site Name	Hybrids
1	Sialkot	FH-810, Soan, Sargodha-2002, Pioneer-30R50, NK-6621, Pioneer-32F10, NK-8441
2	Gujranwala	MMRI yellow, Changeez, Pioneer-3025, Pahari, NK-6385, Pioneer-34N43, NK-8711
3	Hafizabad	Pearl, Shaheen, Pioneer-30Y87, NK-6617, Pioneer-33H25, NK-7002, P-31R88
4	Sheikhupura	Agaiti-2002, Neelum, Pioneer-31R88, NK-6651, Pioneer-32B33, NK6413, Ghouri
5	Nankana Sahib	Sadaf, Synthetic-51, Monsanto-919, Pioneer-31P41, Azam, Kisaan, SH-139
6	Multan	Yousafwala hybrid, Pachaitisufaid, Monsanto-Opener, Pioneer-32T78, Sawan-3
7	Lodhran	Sahiwal-2002, Synthetic-66, Monsanto-974-AW, Monsanto-6525, Babar, Raka-Poshi
8	Bahawalpur	Agaiti-72, Zia, Monsanto-5219, ICI-8288, Agaiti-85, Jalaal-2003, SWL-2002
9	Bahawalnagar	Akbar, Golden-85, ICI-984, Monsanto-6142, YHD-444, PAK-Afghoee, B-202
10	Rahim Yar khan	Synthetic-551, Sultan-6, ICI-993, ICI-11, NK-8001, YHD-555, BS-2, M-919

*Source = Government of Punjab, Pakistan.