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The impact of climate warming and crop management on phenology of sunflower-based cropping systems in Punjab, Pakistan

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ABSTRACT

Understanding the effects of warming trends, genetics, and management on crop phenology is crucial for adaptation against the increasing trend in temperature in the upcoming decades. The goal of this research was to quantify the impact of historic climate warming and management on sunflower phenology (stages and phases). In this project, spring and fall sunflower phenology and daily weather data were obtained for 20 locations in Punjab, Pakistan. We investigated the impact of thermal trend on the phenological stages and phase duration for spring and fall sunflower from 1980 to 2016. The results showed that the mean temperature increased by 0.9 and 0.8 °C decade^{-1} for spring and fall, respectively. The observed phenological stages such as sowing, emergence, anthesis, and maturity dates were earlier for spring by an average of 6.6, 6.3, 3.8, and 2.2 days decade^{-1}and delayed for fall by an average of 5.7, 5.4, 3.1, and 1.8 days decade^{-1}. The observed sowing to anthesis, anthesis to maturity, and sowing to maturity phases were reduced by an average of 2.8, 1.6 and 4.4 days decade^{-1}for spring and 2.5, 1.2, and 3.8 days decade^{-1} for fall. The changes in phenology of sunflower for spring and fall were highly correlated with the enhancement in warming trend during 1980–2016. The CSM-CROPGRO-Sunflower model using standard hybrids for all sites and years showed that the simulated phenology had accelerated due to the change in climate and the simulated phenological dates were earlier than the observed dates. These results indicate that earlier sowing dates for spring, delayed sowing dates for fall, and shifts of varieties that require elevated total growing degree days for the duration of 1980 to 2016 have somewhat mitigated the adverse impact of climate warming on spring- and fall-grown sunflower phenology for ensuring sustainable productivity and ensuring food security.

1. Introduction

Edible oils are an important component of the human dietary needs. Pakistan is characterized as deficient in edible oil production and imports costs upon US$ 2.71 billion (Govt. of Pakistan, 2017). Sunflower ranks third with a 9.19% share in domestic edible oil production followed by cotton and rapeseed/mustard (Govt. of Pakistan, 2017; Amin et al., 2017a; Nasim et al., 2018). Sunflower seeds contain 40-50% oil and 40% digestible protein (Abbas et al., 2017a; Amin et al., 2018). Although sunflower is a crop of temperate regions, it has been grown successfully in a broad range of environmental conditions ranging from humid to semi-arid and arid climates.

Punjab is an important agricultural region with 20.63 million ha of land under cultivation, which is approximately 26% of the land area of Pakistan (Government of Pakistan, 2012; Nasim et al., 2016a; Noreen et al., 2016). The Punjab is divided into two regions, central Punjab, with a mild climate and a mean temperature that ranges from 10.5 to 24.4 °C and average rainfall between300 and 600 mm, and southern

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Table 1
Sunflower cultivars at all locations.

Site Name	Cultivars
Sialkot	Super-25, DK4045, Hysun-777, NKR-72, Peredovic-2
Lahore	Engro-9704, SF-187, PSF-025, DK-3849, Mayak
Okara	FH-75, Super-25, Cheeta, T-562, SF-046, B-37, IS-894
Gujranwala	Beimisal-205, SH-3322, NK-1435, SF-049, M-14, P-64A93
Hafizabad	PARC-92, NK-212, Hysun-39, FH-331, Aritar-93
Sheikhupura	SMH-976, SF-177, PNSF-1, DK-3176, Suncom-1, S-278
Nankana Sahib	NK-265, HS-341, XF-263, FMC-3849, VINMK-8931
Sargodha	SF-287, NK-212, Parsun-12, Gimsun-435, SB-212, Hysun-38
Faisalabad	PI-6480, PARSUN-1, P-9706, Gimsun-476, Suncom-110
Jhang	SMH-095, Hysun-39, Award-3, SF-574, Pioneer-6354
Sahiwal	PARSUN-3, NKS-278, M-3255, Gimsun-7741, SMH-13
Khanewal	Gimsun-456, Hysun-36, Gulshan-98, Allsstarm, HO-1
Multan	Gimsun-6741, Hysun-33, ORI-3B, G-2, Turkish-473, VK-654
Vehari	Pioneer-6470, Gimsun-226, ORI-27B, Nusun-652, HOI-2
Muzaffargarh	NK-274, CM-628, LG-5380, Gimsun-406, VNIMK-8931
Lodhran	Sun-535, PARSUN-2, Nusun-5501, HS-6, Inra-4701
Pakpattan	G-101, Pioneer-6532, Pioneer-3321, FH-330, SMT-1
Bahawalpur	CRN-1435, P-9705, Hysun-33, N4HM-35, SF-187, FH-337
Bahawalnagar	DK-4040, JH-99, DK-4327, N-4334, FH-2, DK-432
Rahim Yar Khan	Pioneer-6435, Gimsun-96, JH-94, NK-265, LM-307

Punjab, with a harsh climate and relatively high temperatures ranging from 18.5 to 31.4 °C and average rainfall of between 75 and 200 mm (Akram and Hamid, 2015; Ahmad et al., 2016; Amin et al., 2017b; Abbas et al., 2017b; Anjum et al., 2016; Ishaq and Memon, 2016).

Climate plays a fundamental role in agricultural systems, and concerns about threats and opportunities associated with climate change are gaining more attention. Noted changes include warmer day and night temperatures, variable rainfall distribution patterns, higher atmospheric $CO_{2,}$ and hydrological imbalances. The General Circulation Models (IPCC et al., 2014; Reddy et al., 2002; Nasim et al., 2017) predict that global mean temperature will increase from 1.4 to 5.8 °C in the present century. The IPCC et al., 2014 noted that 2001–2010 was the hottest recorded decade and 2014 was the hottest year of the 21st century. The intensity, frequency, and duration of extreme temperatures are expected to outpace the current increase in temperature (Fahad et al.,2016a; Fahad et al.,2016b; Fahad et al.,2016c; Fahad et al., 2016d; Meehl et al., 2007). The expected trend in global warming could have a significant impact on the time of occurrence and duration of phenological phases in plants. Generally, it is projected that agriculture of arid, semi-arid, and warmer regions in general of the world are at the greatest risk of climate change (Adams et al., 1998; Ali et al., 2017; Fahad et al., 2014a; Fahad et al., 2014b; Fahad et al., 2015a; Fahad et al., 2015b). Pakistan is very vulnerable to climate change because of its arid and semi-arid climate, which are expected to show a higher increase in temperature compared to the global trends (Rasul et al., 2012; Nasim et al., 2012; Ahmad et al., 2016; Abbas et al., 2017a, b).

Optimum growth and development of sunflower occurs at a temperature range of 26–29 °C (Rondanini et al. 2006; Awais et al., 2017a; Hammad et al., 2017; Jabran et al., 2017b) and sustainable production is under the threat of climate change (Kalyar et al., 2013). In addition to crop management and genetic characteristics (Izquierdo et al., 2002; Wang et al., 2016; Awais et al., 2017b; Jabran et al., 2017a; Nasim et al., 2016a), the shift in phenology of various species has been attributed to climate change (Visser and Both, 2005; Miller-Rushing and Primack, 2008; Parmesan and Yohe, 2003; Gordo and Sanz, 2010; Agostino et al., 2012; Yang et al., 2014; Szabó et al., 2016; Jan et al., 2017; Nasim et al., 2016b). Hence, the changes in phenology over time indicate the impact of climate change and a plant's adoptive responses (Wang et al., 2014). Since, air temperature plays an important role in crop development (Ahas and Aasa, 2006; Kaleem et al., 2009; Hatfield and Prueger, 2015), an earlier occurrence of the phenological stages is expected in warmer climates due an increase in observed temperature of 0.2 °C per decade during the last three decades (Hansen et al., 2006; Ahmad et al., 2016, 2017a, b; Abbas et al., 2017a, b). The upsurge in minimum temperature has often been ignored while evaluating the impact of climate change. However, the changes in minimum temperature are more important to determine the phenology of crops (Hatfield et al., 2011; Nasim et al., 2016c; Mahmood et al., 2017). The timing of flowering and maturity are considered important traits for designing effective adaptation strategies (Forrest and Miller-Rushing, 2010; Nasim et al., 2011; Li et al., 2014). However, so far only a few studies have investigated the impact of global warming on phenology and long-term changes in phenology. These include canola (Ahmad et al., 2017a, b), sugarcane (Ahmad et al., 2016), cotton (Ahmad et al., 2017a, b; Wang et al., 2017), maize (Li et al., 2014; Wang et al., 2016; Abbas et al., 2017a, b), cherry trees (Miller-Rushing et al., 2007), and wheat (He et al., 2015). So, far there has been a lack of information about sunflower phenology. The objectives of this study were (1) to determine the spatial and temporal variability in sunflower phenology and the temperature trend from 1980 to2016 in response to climate change, (2) to use a dynamic crop growth model for separating the effects of climate warming, cultivar shift and crop management on spring and fall sunflower phenology.

2. Materials and methods

2.1. Local climate and phenology

The data regarding the observed phenological events for spring (January-June) and fall (July-November) seasons sunflower from 1980 to 2016 were obtained from the Punjab Agriculture Department (PAD) and the long-term daily weather data for 36 years for 20 selected sites were obtained from the Pakistan Metrological Department (PMD), respectively. Sowing, emergence, anthesis (50%), and physiological maturity dates (50%) were the observed phenological stages for spring and fall sunflower. Using the observed phenological stages, three phenological phases including, sowing-anthesis (S-A), anthesis-maturity (A-M), and sowing-maturity (S-M) were determined. All management practices were based on the local farming community for both spring and fall sunflower crops (Govt. of Pakistan, 2017). Old spring and fall sunflower hybrids were replaced with improved hybrids by the local farmers every five to seven years, with an average of five hybrids for the study period weather station (Table 1). This successive adoption of hybrids was associated with a higher total growing degree day requirement for the main phenological stages.

2.2. Data analysis

Linear regression was used to determine the tendencies for both observed phenological stages and phases for the spring and fall crop in relation to the mean seasonal temperature. Based on the maximum occurrence of the phenological stages for each location, the time frames for determining the thermal trends were obtained. The time frame for the growing season duration, i.e., from sowing to maturity (S-M) was counted from the earliest date of sowing to the latest maturity date during the past four decades for each location (Govt. of Pakistan, 2017). Using his approach, the measured warming trend was not dependent on the analogous variability of the phenological stages and phases. Quantified association of dates of sowing with average monthly temperature for the sowing was determined to assess whether average monthly temperature affected the sowing dates. Subsequent linear regression was applied to determine the influence of changing