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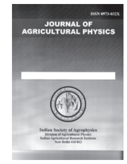

Review Article

Management Strategies for Sustainable Wheat (*Triticum Aestivum* L.) Production Under Climate Change in South Asia – A Review

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ABSTRACT

Wheat (*Triticum aestivum* L.), being a cool season crop, is highly sensitive to increase in temperature. Global warming and climatic changes being experienced during recent decades are resulting in large oscillations in wheat productivity. Increase in minimum temperature has more adverse impact on wheat productivity as compared to maximum temperature. Climatic warming results in enhanced maturity, decrease in grain filling period and hence, reduction in wheat productivity. Similarly, water stress during reproductive growth period of wheat leads to significant reduction in grain yield. Although increase in CO_2 concentration is able to counter balance the negative effect of increase in temperature up to about 1-2°C, but increase in temperature beyond 2°C adversely affects wheat productivity even under elevated CO_2 levels. Different adaptation measures need to be adopted to manage heat and water stress in wheat under changing climatic conditions. Sowing of wheat in the first fortnight of November helps in avoiding terminal heat stress. Improved cultivation systems like zero tillage, bed planting and conventional tillage with mulch produce higher grain yield and improve water productivity of wheat than conventional planting. Irrigation management and retaining crop residue in field are other measures to manage terminal heat stress and improve water productivity in wheat. Breeding strategies need to be stressed upon for developing stress tolerant varieties in view of future climatic challenges. Agroforestry systems should also be adopted to enhance carbon sequestration and improve crop microclimate to sustain productivity under climatic fluctuations. Simulation modelling studies also need to be put in action to explore most effective climate change adaptation / mitigation strategies with respect to climatic variations over different regions. In addition to this, timely availability of accurate weather forecast and agro-advisory can be of great benefit in taking short-term management decisions as per the impending weather conditions.

Key words: Climate change, Wheat productivity, Sowing time, Irrigation management, Mulch application

Introduction

Climate refers to long-term weather patterns of any region. The simplest way to describe climate is to look at average temperature and precipitation over time usually more than 30 years. Useful elements for describing climate include type and timing of precipitation, amount of sunshine, average wind speed and direction, number of days above freezing and extreme weather events etc., whereas climate change is a long-term change in the statistical distribution of weather patterns over long periods of time that range from decades to millions of years. It is not just nationwide, but a global issue. Climate change is caused due to natural and anthropogenic activities. Natural causes include natural fluctuations in the intensity of solar radiation,

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volcanic eruptions and short term cycles *viz*. ENSO, El nino etc. However, during recent decades, most of the climatic changes have occurred as a result of anthropogenic activities like burning of fossil fuels emitting CO_2, methane and nitrous oxide emission from agriculture and industry as well release of CO_2 due to changes in land use and land cover (IPCC, 2014).

Major parameters of climate change are accumulation of green house gases in the atmosphere and resultant global warming, variation in rainfall amount and distribution, variability in solar radiation, drought, floods, heat / cold wave conditions and hailstorms etc. These climatic changes / extreme weather events have a significant effect on crop productivity as these further lead to variations in crop water demand and availability as well as photosynthetic activity and finally crop yields. Direct effects of climate change on crop productivity include effect on plant physiology and morphology and indirect effects include effects on soil fertility, irrigation water availability, disease-insect occurrence, floods and droughts etc. Agricultural production is highly vulnerable to these changes and require human interventions to mitigate or adapt to these impacts. Northern part of Indian sub-continent that includes IGP (indo-gangetic plains), has been placed under high risk zone for heat stress risks in future climates (Teixeira *et al.,* 2013).

Increasing concentration of CO_2 and other green house gases has resulted in a 0.85°C rise in global average temperature over the past 100 years. IPCC (2014) has also predicted a rise in global surface temperature within the range of 0.4–2.6°C by 2046–2065 and 0.3–4.8°C by 2081–2100 relative to the reference period of 1986–2005. Indo-gangetic plains are likely to experience rise in average temperatures by 0.5–1.0°C during mid century (MC) and 3.5–4.5°C during end century (EC) along with increased frequency of extremely wet rainy seasons (Gosain and Rao, 2007). Khan *et al* (2009) estimated that mean temperature in India is projected to increase by 0.4-2.0°C during *kharif* and 1.1-4.5°C in *rabi* by 2070. Similarly, mean rainfall is projected to increase by up to 10 per cent during *kharif* and *rabi* by 2070. At the same time, there is an increased possibility of climate extremes, such as timing of onset of monsoon, intensities and frequencies of drought and floods. Many studies indicate a probability of 10-40% loss in Indian food grain production because of increase in temperature by 2080–2100 (IPCC, 2007; Fischer *et al.,* 2002; Parry *et al.,* 2004).

Wheat (*Triticum aestivum* L.) belonging to family Gramineae (Poaceae), is an important cereal crop of India, ranking second after rice with respect to area and production. It is the staple food of billions of people. In India, wheat was grown on 30.79 million hectare with a production of 98.51 million tonnes and productivity of 3.20 tonnes/ha, whereas in Punjab, it was grown over an area of 35.12 lac hectares with a production of 178.30 lac tonnes and productivity of 5.08 tonnes/ha during 2017-18 (Anonymous, 2018). Large weather fluctuations being experienced during recent decades result in large oscillations in wheat productivity. Punjab has also experienced large weather variability affecting wheat productivity in the region. Kingra (2016) has reported significant increasing trend in minimum temperature (0.06°C $year^{-1}$) and decreasing trend in sunshine hours (0.03 hrs day^{-1}) and wind speed (0.03 km hr^{-1}) during wheat growing season in central Punjab. In the years to come, precipitation is projected to increase by 13-22%, annual maximum temperature by 1.0-1.8°C and annual minimum temperature by 1.9-2.1°C in the state (Punjab State Action Plan on Climate Change, 2012), which can have severe implications on wheat productivity in the region.

Future impacts of climate change in India include decrease in snow cover, rising sea level, increased frequency and intensity of floods and erratic monsoon rainfall with serious effects on rainfed agriculture. Wheat production in India has been projected to decrease by 4-5 mt with 1°C rise in temperature (Aggarwal, 2008). Kumar *et al*. (2014) also projected that climate change will reduce the wheat yield in India in the range of 6 to 23% by 2050 and 15 to 25% by 2080. Even though the magnitude of the projected impacts is variable, the direction is similar in the climate scenarios of both a global and a regional climate model. Negative impacts of climate change are projected to be less severe in low than in high-emission scenarios. Thus, adverse effects of global warming and climatic changes on wheat productivity are inevitable in the years to come. Under such conditions, adaptation measures need to be developed to manage the climate variability impact on wheat productivity. Based on the review and analysis of relevant literature, an overview of recent climatic changes and their effect on wheat productivity has been discussed in the present manuscript. An attempt has also been made to identify and discuss various adaptation / mitigation strategies to manage the climate change impact to sustain wheat productivity in the south-east Asian region.

Climatic requirements of wheat

Wheat is a cool season crop. Cool weather conditions during vegetative phase and warm during maturity are favourable. It requires minimum, optimum and maximum cardinal temperature of 3-4.5°C, 20-25°C and 30-32°C, respectively, for its growth and development. However, optimum range of temperature for germination and vegetative growth of winter wheat is 15-20°C. Mean maximum temperature of 25°C and mean minimum temperature of 12°C is considered optimum for grain development (Reddy and Reddy, 2007). Its temperature requirement varies under different growth stages. During germination the mean temperature requirement is 18-20°C, for growth and development 15-20°C, for flowering 18-24°C and for grain development 23-25°C. High temperature during rapid growth results in poor tillering, low number of effective tillers, poor growth rate, short shoot size, low leaf area index, short ears with low number of spikelets, low grain weight and poor quality. Presently, high temperature during grain filling period is being observed as one of the major environmental constraints limiting the grain yield of wheat. Temperature above 27°C cause under development of anthers and reduce the viability of pollens and results in terminal heat stress if it exceeds 31°C during grain filling stage. Total water requirement ranges between 350–550 mm. Bright sunny days with dryness and cooler nights during ripening period give better sized quality grains (Pillai and Nair, 2010).

Effect of climate change on wheat productivity

Recent climatic changes have made significant impact on wheat productivity. Large year-to-year variations in wheat productivity are being observed resulting in large oscillations in wheat productivity. Kingra *et al.* (2018) investigated the effect of different determinants (climate, fertilizer and irrigation) influencing wheat yield and observed that minimum temperature explained 44% variability in yield. Out of the remaining 56% variability, 44% was explained by irrigation availability and 7% by fertilizer application. Thus, in view of the changing climatic conditions, large yield losses have been predicted due to warming scenarios in future.

Effect of temperature

As wheat yields are highly sensitive to increase in temperature, thus the climatic warming conditions are adversely affecting its productivity especially in the warmer regions. Rao *et al.* (2015) reported that wheat yields in India appear to be becoming more sensitive to minimum temperature especially during post-anthesis period. Mean wheat yields for the period 1980–2011 declined by 7% (204 kg ha^{-1}) for 1°C rise in minimum temperature. Exposure to continual minimum temperature exceeding 12°C for 6 days and terminal heat stress with maximum temperature exceeding 34°C for 7 days during post-anthesis period have been observed as the thermal constraints in achieving high productivity. Samra *et al.* (2012) observed an average yield loss of 217 kg ha^{-1} (4.5%) during a heat wave year and a gain of 356 kg ha^{-1} (7.4%) during a cold wave year. Between the two continuous cold wave years, productivity gain in the Punjab state, in the relatively colder year (2011–2012) was higher by 400 kg ha^{-1}. However, Bala *et al.* (2014) revealed that the high temperature is a major determinant of wheat development and growth and causes yield loss in many regions of the world. High temperature significantly decreased all traits especially grain yield (26% and 54.2%), 1000-kernel weight (24% and 31%) and grain filling duration (3% and 9%) in tolerant and susceptible genotypes, respectively. Grain yield (54%) was most affected and grain filling duration (9%) was least affected by heat stress.

Rahman *et al.* (2009) reported a significant reduction in number of tillers per plant in different genotypes of wheat with increase in day and night time temperature by 5°C above normal in different genotypes of wheat. Enhanced temperature also resulted in significant reduction in crop duration (with decrease in number of days for booting by 14–20%, heading by 18–25%, anthesis by 18–27% and maturity by 28–37%), number of grains per spike (upto 21%) and grain weight (upto 29%) in different genotypes. Kaur and Hundal (2010) reported significant reduction in grain yield of wheat due to high temperature during February and March. Mian *et al.* (2007) also concluded that yield components were significantly affected by high temperature during grain filling period. High temperature from anthesis to maturity caused high transpiration rate and forced maturity resulted in low production. It caused poor fertilization and poor grain development which resulted in poor yield of wheat. They observed upto 31% reduction in number of grains per spike and 55% reduction in grain yield due to high temperature after anthesis.

Prasad *et al.* (2008) reported that high night time temperature adversely affected the phenology of wheat. Although the effect was non-significant upto flag leaf emergence, but high temperature at anthesis and seed setting lead to reduction in period to attain physiological maturity by 10 days and induced spikelet sterility by 26%. Mohhamad *et al.* (2011) also observed significant decrease in grain yield and number of grains per ear due to increase in temperature in winter wheat. Kazmi and Rasul (2011) observed significant correlation between minimum temperature during first 10 days of January and wheat yield. They also observed significant correlation between heat units at heading and grain yield of wheat. Jalota *et al.* (2014) reported reduction in crop maturity by 23–30 days over different locations in Punjab by end of the century. Garatuza-Payan *et al.* (2018) also reported 39 and 33% reduction in Biomass and grain yield of wheat under warming by 2°C in Mexico. Prasad *et al.* (2018) observed decrease in wheat productivity by 9.4 to 33.1% with increase in temperature from 1 to 3°C.

Effect of CO_2

Increase in CO_2 concentration increases the rate of photosynthesis and decreases stomatal conductance, which leads to decrease in rate of water loss from leaf surface, thus results in increased crop and water productivity. Hatfield *et al.* (2011) reported 35% increase in leaf photosynthesis, 31% increase in grain yield and 38% decrease in stomatal conductance of wheat with increase in CO_2 concentration to 660 ppm. However, under natural conditions, increase in CO_2 concentration leads to green house effect and global warming and is thus, always associated with increase in temperature. Under such conditions, increased CO_2 level can counter balance the negative effect of increase in temperature upto some extent. Kaur and Hundal (2009) reported that increase in CO_2 concentration upto 600 ppm can counter balance the effect of increase in temperature upto 1-2°C, but if temperature increases beyond 2°C, even under increased CO_2 level, there will be yield loss. Wilcox and Makowski (2014) also reported that the effect of increase in temperature and decrease in precipitation can be nullified at CO_2 concentration of 720 ppm. Xiao *et al.* (2018) reported declining trend in wheat yield without considering increase in CO_2 concentration under future climate scenarios, however, under increased CO_2 concentration, increase in wheat yield was observed for most of the locations under study in China. The study provided a clear picture of the adverse effects of climate change on wheat growth and yield if no adaptation measures to climate change were taken.

Effect of moisture / rainfall

Although wheat crop has considerable resistance to drought, but period from shooting to heading is highly sensitive to moisture stress (Pillai and Nair, 2010). Well distributed rainfall of 350-400 mm is required during the crop period. Saxena *et al.* (1996) reported that moisture stress adversely affects the water potential, photosynthesis and grain yield of wheat. Under moisture stress conditions water potential decreases leading to reduction in photosynthesis and transfer of photosynthates to grain, which results in lower grain weight and number and hence, reduced grain yield. However, reduction in grain yield varied from 12–48% in different cultivars of wheat. Yadav *et al.* (2001) also reported that soil moisture stress results in loss of turgor, leading to decrease in stomatal conductivity, photosynthesis and grain yield. Reduction in grain yield could be attributed to its harmful effect on pollination which significantly reduced the number of grains/plant and their size, although different varieties responded differently to stress levels. Kingra and Mahey (2013) also reported reproductive growth period of wheat to be most sensitive to moisture stress. Hatfield and Dold (2018) found the primary cause of yield gaps between attainable and actual yields to be inadequate precipitation during grain-filling period in US Great Plains and emphasized the need for adaptation practices that could increase water availability to the crop coupled with positive impact derived from other management practices viz. cultivars, fertilizer management etc. However, heavy rains during grain filling and maturity also have adverse effect on quality and quantity of wheat yield. Kingra (2016) reported that low relative humidity, rainfall and number of rainy days during the reproductive growth period of wheat covering the months of February and March have been found favourable for higher grain yield.

Effect of solar radiation

Wheat is a long day plant i.e. it requires long days during flowering stage and short days during vegetative stage. It requires >12 hours daylight for flowering (Pandey and Sinha, 2006). If photoperiods are not proper it results in delayed flowering which leads to poor yield. Saturation light intensity of wheat is 5300 ft. c. (Gill, 2000; Srivastava, 2006). Ahmed and Hasan (2011) observed linear increase in wheat yield with increase in solar radiation at anthesis and maturity. Mahi (1996) reported 7% increase in wheat yield with increase in solar radiation by 10% under Punjab conditions, but grain yield declined under decreasing amounts of solar radiation. Prasad *et al.* (2018) reported that wheat productivity increased by 0.9 to 3.1% with increase in 1 to 3 MJ m^{-2} day^{-1}, whereas decreasing the radiation by same amount decreased wheat yield by 1.2 to 3.6%.

Sustainable management strategies

It is evident that wheat productivity is expected to be adversely affected by climatic changes. Thus, sustainable adaptation measures need to be adopted to manage the climate variability impact to sustain crop productivity and ensure food security in future. Selection of heat tolerant varieties, change in sowing time, tillage practices, planting methods and water management etc. need to be followed to deal with the situation. In addition to this, adopting agroforestry systems modelling and following weather forecast and agro-advisory are other optioins which can be of great benefit.

Date of planting

Timely sowing of wheat crop generally gives higher yield as compared to late sown crop. Late sown wheat crop faces high temperature stress during ripening phase. Late planting reduces the tillering period and hot weather during critical period of grain filling lead to forced maturity thereby reduces the grain yield. Solanki (2012) reported higher grain yield in November sown wheat crop as compared to December sown crop. Mukherjee (2012) reported maximum grain yield and yield attributing characters in 15th November sown crop and a significant reduction with delay in sowing. Dhyani *et al.* (2013) also observed significantly higher grain yield and harvest index in timely sown wheat cultivars as compared to late sown conditions. Samra and Dhillon (2002) reported significantly higher plant height, tiller number, grain yield, straw yield and 1000 grain weight of wheat sown on 15th November as compared to 20th December. Sharma *et al.* (1999) reported higher grain yield in 3rd November sown crop as compared to 15th November and 15th December. Singh *et al.* (2016a) reported that sowing of wheat on 29th October under central Punjab conditions improved its heat use efficiency as compared to 12th November and 28th November sown crop, which is essentially required under climate warming scenarios.

Although wheat experiences heat stress to varying degrees at different phenological stages, but it is more detrimental at reproductive stages as it directly affects grain size and weight. Earlier sowing of wheat has been observed as beneficial in managing terminal heat stress. The crop witnessed favourable microclimate as temperature was lower during later growth stages resulting in higher yield and yield attributing characters (Singh *et al*. 2016b). Singh *et al*. (2018) observed more negative accumulated stress degree days (ASDD) under 5th November sown crop as compared to that sown on 20th November and 5th December. The grain yield was also highest under 5th November sowing (50.8q/ha), which was statistically at par with 20th November (49.0q/ha) but was significantly higher than 5th December (42.9q/ha) sown crop. Thus, adjustment in sowing time is helpful in avoiding terminal heat stress and improving grain yield and heat use efficiency of wheat.

Cultivation systems

It has been observed that conservation agriculture viz. zero tillage, bed planting and conventional tillage with mulching produce higher grain yield of wheat than conventional tillage. Su *et al.* (2007) reported that winter wheat yields were significantly affected by the tillage methods. The average winter wheat yields over 6 years on no tillage or subsoil tillage plots were significantly higher than that in conventional tillage or reduced tillage plots. Yadav *et al.* (2002) reported higher number of grains per spike and spike density of wheat planted on raised beds than conventionally sown wheat on flat surface. The lower tiller and spike density on bed were compensated by more grains per spike and higher grain weight (Singh *et al.* 2001, Dhillon *et al.,* 2004; Sikka *et al.,* 2004). Dhillon *et al.* (2005) recorded significantly higher yield attributes and grain yield of wheat under bed planting as compared to conventional sowing. Noorka and Tabasum (2013) revealed that the raised bed planting method may be less susceptible to adversities of climate change because it portrays better ability to plant roots anchorage on beds, ability to withstand water stress and may help to conserve genetic resources via the promising genotype. Thapa *et al.* (2019) concluded that adoption of no tillage, with retention of residue following the soybean – wheat cropping system has significant positive effect on yield and yield attributing characters of wheat crop

Bed planting also results in water saving. Singh (1995) recorded 25 per cent saving of post-sowing irrigation water in bed planting system of wheat establishment over border method of irrigation used in conventional flat sowing. Aggarwal and Goswami (2003) recorded 30, 20 and 5 per cent saving of water applied at first, second and third irrigation under bed planted system, respectively compared to conventional system. Bhat and Mahal (2006) reported significantly higher grain yield of wheat under bed planting as compared to flat planting and timely sown condition (Roy *et al*. 2018). Hossain *et al.* (2006) also reported higher grain yield and harvest index of wheat under bed planting. Le Bassonais and Arrouays (1997) reported significantly higher grain yield of wheat with 3 wheat rows per bed followed by conventional planting and two wheat rows per bed. Quanqi *et al*. (2008) observed significant increase in radiation use efficiency and reduction in lodging under fully irrigated conditions in case of bed planting in 70, 80 and 90 cm bed width as compared to conventional planting. Kingra and Mahey (2013) reported higher soil moisture use under flat planting as compared to bed planting in wheat. Dhaliwal *et al.* (2019) revealed that intercepted photosynthetically active radiation (PAR) was 4-5% higher in E-W than N-S row direction, which contributed 1.67 q/ha higher grain yield. Better utilization of solar radiation was also observed in 15.0 cm row spacing as compared to 22.5 and 30 cm.

Mulch application

Organic mulches provided better soil water status and improved plant canopy in terms of biomass, root growth, leaf area index and grain yield, which subsequently resulted in higher water and nitrogen uptake and their use efficiencies (Singh *et al.,* 2011a). Brahma *et al.* (2007) reported increase in yield and yield attributing characters of wheat with mulch application and anti-transpirant spray as compared to control. Jat *et al.* (2008) reported that retaining residue into field decreases canopy temperature and hence, is helpful in beating terminal heat stress in wheat. Singh *et al.* (2011b) reported significant increase in wheat grain yield with mulch application under sub-optimal irrigation. Buttar *et al.* (2018) also reported higher wheat yield in earlier sown wheat with straw mulch application @ 5 t/ha. Dhaliwal *et al.* (2019) observed 0.5°C lower canopy temperature, 4-5% higher soil moisture and significantly higher grain yield of wheat under mulch. Hence, mulch application performs dual task of managing heat and water stress in wheat.

Irrigation management

Irrigation management and retaining crop residue are other measures to manage terminal heat stress and improve water use efficiency of wheat. Gupta *et al.* (2018) explained that decline in wheat yield during recent years is mainly attributed to shortening of growing period, decrease in photosynthesis ability and increase in respiration, thus demanding more irrigation water supply. Khan *et al.* (2013) reported that for obtaining maximum yield of wheat, the crop may be irrigated at five weeks interval. Excessive and earlier irrigation may be harmful for the optimum yield if seasonal rainfall is > 330 mm. Brahma *et al.* (2007) concluded that with increase in irrigation all the yield attributing characters *viz.* ear length, number of grains per ear, effective tillers, grain yield, straw yield, 1000 grain weight and harvest index increased. In addition to this, irrigation management also helps in regulating canopy temperature and alleviating heat stress. Kingra *et al.* (2013) observed higher canopy temperature in rainfed as compared to irrigated wheat crop. Increase in canopy temperature depression (T_c-T_a) was observed with increase in the frequency of irrigation (Fig. 1). In the rainfed crop, sensible heat flux was much higher than latent heat during mid day, but under the well watered treatment, latent heat flux was higher than sensible heat flux under both conventional and bed planting. Sharma and Pannu (2008) also reported decrease in canopy temperature depression under restricted irrigation. Xiao *et al.* (2007) reported that supplemental irrigation might play an important role in maintaining yields of crops in a pea-spring wheat-potato rotation system affected by climate warming. Kingra *et al.* (2011) also observed increase in heat use efficiency of

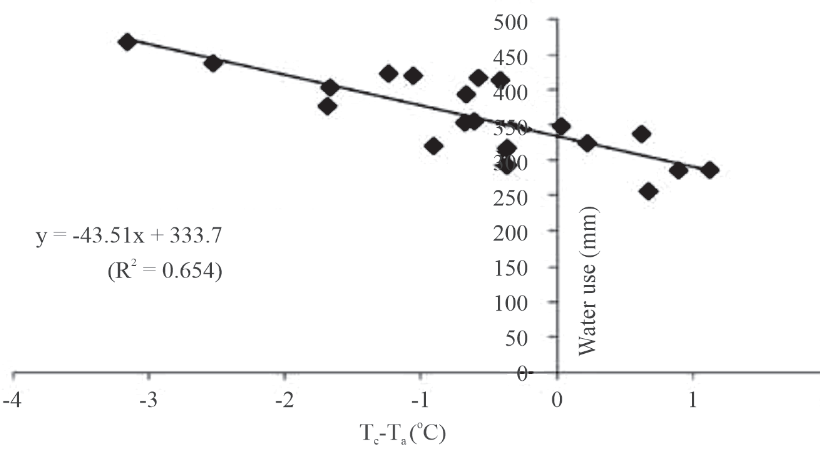

Fig. 1. Relation between canopy – air temperature difference (T_c-T_a) and water use in wheat (Kingra *et al.* 2013)

Table 1. Thermal time requirement (°C days) and heat use efficiency (kg ha^{-1} °C^{-1} day^{-1}) of wheat under different irrigation levels

Treatments	Seed yield (kg ha^{-1})	GDD (°C days)	Heat use efficiency (kg ha^{-1} °C^{-1} day^{-1})
	***Rabi* 2006-07**		
I_0	3099	1698	1.83
I_1	4043	1721	2.35
I_2	4693	1746	2.69
I_3	4583	1746	2.62
I_4	4922	1765	2.79
	***Rabi* 2007-08**		
I_0	2799	1665	1.68
I_1	3344	1697	1.97
I_2	3962	1712	2.31
I_3	4347	1712	2.54
I_4	4736	1727	2.74

I_0, I_1, I_2, I_3 and I_4 refer to 0, 1, 2, 3 and 4 post-sowing irrigations, respectively
Source: Kingra *et al.* (2011)

wheat under adequate water supply indicating irrigation management as effective strategy to beat water and heat stress in wheat (Table 1).

Evans and Sadler (2008) concluded that redesigning total irrigation systems for higher efficiency, successfully treating and reusing degraded waters, reducing evaporation losses, introducing site-specific applications, implementing managed-deficit irrigations, and employing engineering techniques to minimize leaching and water losses to unrecoverable sinks. Ali *et al.* (2007) reported the highest water productivity, where deficits were imposed at maximum tillering and flowering to soft dough stages of growth period, followed by single irrigation at crown root initiation stage.

Breeding for stress tolerant cultivars

In view of the future climate change scenarios, breeding of stress resistant / tolerant cultivars seems to be the need of the hour. Identification of stress tolerant genes and their incorporation into high yielding varieties is a challenging task for the breeders and biotechnologists. The latest breeding and biotechnological techniques are required to put in action to develop stress resistant cultivars to face challenges of future climate scenarios especially cool season crops like wheat.

Agro-forestry systems

Adopting agro-forestry systems is another important strategy to manage climate change impacts on wheat productivity. Agro-forestry systems can perform dual purpose of increasing carbon sequestration and modifying crop microclimate by reducing daytime canopy temperatures and improving moisture availability, thus providing both advantages of climate change mitigation and adaptation. Kumar and Singh (2014) examined the mitigation potential of agro-forestry in the humid and sub-humid tropics and highlighted the important role of agro-forestry in climate change adaptation, particularly for small holder farmers. They suggested that poplar based agro-forestry system could be a great option in the light of climate change as well as from financial and diversification point of view. Kumar *et al* (2019) compared response of wheat under open farming and poplar based agroforestry system and observed that above-ground, below ground and total biomass, carbon stock and carbon sequestration were significantly higher in agroforestry system compared to open farming.

Crop simulation modeling

Crop simulation modeling studies can be of great benefit to assess the impact of climate change scenarios on wheat productivity, to evaluate sensitivity of different regions to these impacts and to explore most effective options for managing climate change impacts. This otherwise requires very expensive infrastructure to conduct research under controlled climate conditions and poses a serious hindrance to research studies especially in the developing countries. However, crop simulation modeling can supplement these requirements and can be used quite effectively under climate change for impact and management. Rezzoug *et al.* (2008) discussed that crop simulation models are essential tools to design management practices to mitigate adverse conditions. They can be used to predict crop yield expectancies under limjited environmental resources and various management scenarios. Ghanbari and Taei-Semiromi (2012) conducted regional wheat yield gap analysis for potential and water-limited production situations in the cold semi-arid climate of Iran by using WOFOST model and observed temperature as the decisive factor for yield during rainfall seasons limiting the crop growth period and demonstrated that WOFOST model could be used to analyse cropping systems and accurately simulate regional wheat yields in cool semi-arid climates. Simulation study conducted by Sun *et al*. (2015) implied that Xinjiang and inner Mongolia are more sensitive to climate change than other regions in China and priority should be given to design adaptation strategies for winter wheat planting. Beck *et al.* (2017) reported sowing of wheat on 25th November to be most appropriate in view of projected climate scenarios by 2050 under central Indian conditions by using CERES-wheat model.

Weather forecast and agro-advisory services

Availability of effective weather forecast and agro-advisory services is another important step for managing climatic risks in wheat production. Based on the weather forecast and agro-advisory bulletins farmers can take short-term decisions of irrigation application, spray application etc. to avoid wastage of costly inputs and improve crop productivity by saving it from adverse weather conditions. For instance, withholding irrigation application in view of prediction of rainfall / dust storms, which is quite common under Punjab conditions during the month of March coinciding with maturity period of wheat crop, can save electricity and reduce cost of cultivation along with improving wheat productivity by saving the crop from lodging and thus avoiding yield losses. Dakhore *et al.* (2008) revealed that by adopting weather based agro-advisory bulletins farmers had significantly reduced input cost and increased net returns. Vashisth *et al.* (2013) also reported that weather forecast and agro-advisories help in increasing the economic benefit to the farmers by suggesting them suitable management practices according to the weather conditions.

Conclusion

Undoubtedly, the changing climate scenarios are posing severe threat to wheat productivity in different regions. Different climatic parameters namely, temperature, moisture, sunlight and wind etc. during crop growing period, especially during reproductive growth phase, have significant effect on wheat productivity. Thus, deviations in these parameters under global warming and changing climatic scenarios will have adverse impact on wheat productivity especially in the tropical and sub-tropical areas. Different mitigation / adaptation measures viz. alteration in sowing time, planting method, mulch application, irrigation management etc. need to be adopted. In addition to this, breeding for stress tolerant cultivars, using crop simulation models to develop management strategies under different climate change scenarios, adopting agro-forestry systems and following weather forecast and agro-advisories for taking tactical short term decisions is the need of the hour to sustain wheat productivity under changing climatic conditions.

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