Chapter

Climate Change Impacts and Adaptation Strategies for Agronomic Crops

Ishfaq Ahmed, Asmat Ullah, M. Habib ur Rahman, Burhan Ahmad, Syed Aftab Wajid, Ashfaq Ahmad and Shakeel Ahmed

Abstract

Climate change is a serious threat to agriculture and food security. Extreme weather conditions and changing patterns of precipitation lead to a decrease in the crop productivity. High temperatures and uncertain rainfall decrease the grain yield of crops by reducing the length of growing period. Future projections show that temperature would be increased by 2.5°C up to 2050. The projected rise in temperature would cause the high frequent and prolong heat waves that can decline the crop production. The rise in temperature results in huge reduction in yield of agronomic crops. Sustaining the crop production under changing climate is a key challenge. Therefore, adaptation measures are required to reduce the climate vulnerabilities. The adverse effect of climate change can be mitigated by developing heat tolerant cultivars and some modification in current production technologies. The development of adaptation strategies in context of changing climate provides the useful information for the stakeholders such as researchers, academia, and farmers in mitigating the negative effects of climate change.

Keywords: climate change impacts, climate change projections, adaptation strategies

1. Introduction

Climate change and variability are the real threats to agriculture and food security [1, 2]. Extreme weather events and uncertainty in rainfall patterns are negatively affecting the agricultural crops [3, 4]. The evidences of global trend in rainfall are unclear due to large regional gaps in spatial coverage and temporal shortfalls in the data. Owing to these changes, the drought is more prevailing in many regions of the world including Pakistan [5].

Finding evidences reported that high temperature and uneven distribution of rainfall have negative effects on crop productivity all over the world [6]. These changes in weather and climate are likely to affect the food security of developing world where a large fraction of ever-increasing population is already fronting hunger, insecure and unhealthy food [7]. Warming of weather and climate systems can results in highly corresponding changes in the occurrence of extreme events including rise in temperature, uneven rainfall patterns [4]. These extreme events occur due to shift in their distribution, or to change in the shape of distribution. Various studies suggest that a shift in mean accounts for much the change in observed temperature extremes [8]. Comparisons of various studies showed that both daily maximum (Tmax) and minimum (Tmin) temperatures have shifted toward higher values in all regions. These shift in temperatures and rainfall significantly effected the cropping patterns, crop yields and phenology [9].

The Intergovernmental Panel for Climate Change (IPCC) has found evidences of accelerated global warming, climate variability and change since the early 1990s. The IPCC reported that average global temperature in the last 100–150 years has increased by 0.76°C [10]. The variability in temperature altered the phenology of crop, i.e., leaf development, anthesis, harvest, fruit production and in asynchrony between anthesis and pollinators. The variable temperature range resulted in high respiration rates, reduction in pollen germination, shorter grain filling period, lesser biomass production and low yields [4]. High temperature above 35°C in combination with high humidity and low wind speed caused a 4°C increase in temperature, resulting in floret sterility in cereals and fruits [6]. Climate change impact assessment provides the scientific foundation for the development of adaptations to offset the negative impacts of climate change. Keeping in views, the current study was planned to assess the impacts of climate change and adaptations strategies for agronomics crops.

2. Projections of climate change across the globe especially in ASIA

World faces dreadful challenges due to changing climate as it is indicated by climatic models that global surface temperature is likely to exceed 1.5°C relative to 1850–1900 for all representative concentration pathways (RCP) scenarios for the end of the twenty-first century [11]. It is likely to exceed 2°C for RCP 6.0 and RCP 8.5 and warming will continue beyond 2100 under all RCP scenarios. Increase of global mean surface temperatures for 2081–2100 relative to 1986–2005 is projected to likely be increased 0.3–1.0°C (RCP 2.6), 1.1–2.6°C (RCP 4.5), 1.4–3.1°C (RCP 6.0), 2.6–4.8°C (RCP 8.5) by the of the twenty-first century. It is projected that temperature will increase drastically in arid areas of Pakistan and India and western part of China [11]. Models predictions indicated that erratic rainfall with greater intensity would increase across the region, but higher intense rainfall will occur during summer monsoon season. Increase in aridity in South and Southeast Asia is projected due to decline in winter rainfall. Sea level will rise to 3–16 cm by 2030 and 7–50 cm by 2070 across the globe due to climatic abnormalities and in relation with regional sea level variability [11].

It is evident from the facts that lives of millions rural poorest people in Asia are highly vulnerable to climate change. There are evidences of prominent increase in intensity and frequency of many extreme events such as heat waves, erratic and uncertain rainfall patterns and more number of hot days, sustained dry spells, tropical cyclones and dust storms in the region. These countries accounted for 91% of the world's total death and 49% of the world's total damage due to natural disasters in the last century. South Asia is the most food insecure region with 262 million malnourished people in the world [6, 12]. Discussed facts showed (**Table 1**) that rural communities that already live in remote dry lands and deserts with inadequate natural resources are most prone to climate change. Agricultural systems being affected by abnormal climatic variables that disturbs the biological, physical and chemical processes of the systems. Number of hot days and warm nights are likely

Crops	Country/continent	Yield reduction (%)	References
Wheat	Australia	−32	[13]
	Iran	−37	[14]
	Worldwide	−5.5	[7]
	Mexico	+25	[15]
	China	−17.5	[16]
	Asia	−7.7	[17]
	India	−5.2	[19]
	Pakistan	−50	[20]
	Turkey	−20	[21]
Rice	India	−7	[22]
	Indonesia	−11	[23]
	India	−8	[24]
	Asia	−6.3	[25]
	Italy	−12	[26]
	Japan	−11.3	[27]
	Nepal	−24	[28]
Maize	Portugal	−17	[16]
	Ghana	+12	[29]
	Africa	−20	[30]
	USA	−50	[31]
	Ethiopia	−4.7	[32]
	China	−46	[33]
	Africa	−32	[34]
	Pakistan	−27	[4]
	China	−30	[35]
	USA	−27	[36]

Table 1.
Impact of climate change on cereal crop production.

to increase in the Asia from 1961 to 2003 and reduction in cool days and nights was observed especially in the years after the start of El Nino [37]. Tropical cyclones frequency and intensity has increased in Pacific from last few decades [38].

3. Impact of climate change on crop production

Global atmospheric concentrations of greenhouse gases have significantly increased relative to pre-industrial times [13, 39, 40]. As a result, greenhouse gas forcing is the main cause of the warming of the atmosphere during the past decades [14, 41, 42]. This warming is expected to substantially alter the climate system and change global food production, mainly because temperatures are predicted to increase which in turn will alter the precipitation pattern and increase the frequency of extreme events such as drought [15, 43–45]. Man-made greenhouse gas emissions as a result of industrialization and urbanization have made significant contributions to global warming and further changes in the global climate. As a result, global temperature rose by 0.83°C from 1906 to 2010 [10]. Global warming also causes changes in precipitation levels and patterns due to higher evapotranspiration and water vapor amounts in the atmosphere with several implications for the global hydrological cycle [16, 46]. As the major water consumer of the developing world and some developed countries, agriculture is one of the most vulnerable water sectors to climate change [17, 18]. Dramatic population growth, associated with reduction of productive land area and water resources, exerts extra pressure on the agricultural sector. To ensure sustainability of agriculture, studying the possible climate change impacts on this sector is essential [9, 19, 47].

Rate of plant growth and development is dependent upon the temperature surrounding the plant and each species has a specific temperature range represented by a minimum, maximum, and optimum [48–50]. The expected changes in temperature over the next 30–50 years are predicted to be in the range of 2–3°C Intergovernmental Panel for Climate Change [10]. Heat waves or extreme temperature events are projected to become more intense, more frequent, and last longer than what is being currently been observed in recent years [51, 52]. Extreme temperature events may have short-term durations of a few days with temperature increases of over 5°C above the normal temperatures [53]. Extreme events occurring during the summer period would have the most dramatic impact on plant productivity. A recent review by Barlow et al. [54] on the effect of temperature extremes, frost and heat, in wheat (*Triticum aestivum* L.) revealed that frost caused sterility and abortion of formed grains while excessive heat caused reduction in grain number and reduced duration of the grain filling period. Analysis by [55] revealed that daily minimum temperatures will increase more rapidly than daily maximum temperatures leading to the increase in the daily mean temperatures and a greater likelihood of extreme events and these changes could have detrimental effects on grain yield. If these changes in temperature are expected to occur over the next 30 years then understanding the potential impacts on plant growth and development will help develop adaptation strategies to offset these impacts [56, 57].

Previous studies of climate change impacts on agriculture, using crop yield simulation models [9, 58–60].or statistical models suggest that climate change will substantially affect productivity of major staple food crops such as maize, because growth and development of crops are mainly dependent on sunlight, temperature, and water [22, 23, 61]. Climate change may modify precipitation, soil water, runoff, and may reduce crop maturation period and increase yield variability and could reduce areas suitable for the production of many crops [24, 62, 63]. Climate change might limit crop production (the amount of a crop that is harvested in a farm, region, state, or country in kilograms or tons) in many areas [64–66].

Temperature increases affect most plants, leading to crop yield reduction and complex growth responses [25, 46, 67]. Nevertheless, the impact of increasing temperatures can vary widely between crops and regions. For example, a 1°C increase in the growing period temperature may reduce wheat production by about 3–10% [68], winter wheat productions may be decreased by 5–35%, respectively, under the future warmer and drier conditions [21, 26], and corn yield may be reduced by 2.4–45.6% due to higher temperatures [27, 69]. Even if precipitation is unchanged, the crop production may decrease by 15% on average due to the reduction in crop growth period and increased water stress as the result of higher temperature and evapotranspiration (Schlenker et al. [63]; Yang et al. [16]; Khanal et al. [28]) expected precipitation reductions in arid and semiarid regions of the world, where water is already limited, can have dramatic impacts on crop production [32–35]. For example, in northwestern Turkey, winter wheat yield may decline more than 20% under future climate change because the growth periods can be shortened as a result of increased temperature, exacerbated by a reduction in precipitation [21, 29–31]. Higher reduction in wheat yield of 50% was found in Pakistan as shown in **Table 2**. In some other areas, climatic change might have positive influences on agricultural crop yield, i.e., in dry areas rainfall enhances under wet climatic warming can lead to improved crop productions like in Mexico the wheat yield would be increase by 25% in future (**Table 2**). Maize, rice, winter wheat and potato crop yield can be enhanced with increasing air temperature and rainfall in the Plain of North China [73]. In Ghana maize yield would be increase by 12% in future (**Table 2**). The impact of climate change on sugarcane and cotton is shown in **Table 3**. Higher reduction in cotton yield of 17% and sugarcane yield of 40% was found at USA (**Table 3**). However, some positive impacts of climate change on sugarcane yield were found in few countries such as Brazil and Australia (**Table 3**). The impact of climate change on coarse grain, oilseed and other miner crops such as pearl millet, sorghum and sesame are shown in **Table 1**. Huge reduction in coarse grain and other

Crops	Country/continent	Yield reduction (%)	References
Cotton	China	−5.5	[48]
	USA	−17	[49]
	Africa	−7	[52]
	USA	−9	[51]
	Pakistan	−8	[53]
	Burkina Faso	−13	[56]
	Australia	−17	[59]
Sugarcane	Brazil	+15	[70]; [65]
	Switzerland	−9	[71]
	Australia	+20	[72]
	Africa	+11	[46]
	USA	−40	[66]
	Brazil	−27	[65]
	India	−30	[64]

Table 2.
Impact of climate change on other crop production.

Countries	Coarse grains	Oilseeds	Other crops
China	−22 to 2	−12 to 12	−22 to 2
Philippines	−17 to −3	−10 to 4	−17 to −3
Thailand	−17 to −3	−10 to 4	−17 to −3
Rest S+E Asia	−17 to −3	−10 to 4	−17 to −3
Bangladesh	−17 to −3	−10 to 4	−17 to −3
India	−17 to −3	−15 to 4	−17 to −3
Pakistan	−17 to −3	−15 to 4	−17 to −3
Rest S Asia	−17 to −3	−15 to 4	−17 to −3

Table 3.
Productivity shock due to climate change on rice, wheat, and coarse grains by 2030.

crops were found in china up to 2030. However, higher losses in oilseed crops were observed at India and Pakistan as shown in **Table 1**.

4. Adaptation strategies for agronomic crops

Climate change adaptation is the action to global warming, which helps to reduce the vulnerabilities in the social and biological system. The main objective of adaptation strategy is to build the resilient in societies against climate change [74].

Agriculture sector is highly vulnerable to changing climate. Extreme weather conditions and changing patterns of precipitation affects the crop development, growth and yield of crops. High temperature at critical growth stages could reduce the grain filling duration caused the grains sterility and consequently yields reduction. [4]. To avoid the risks in agriculture associated with climate change (CC), adaptation is the key factor that could help to mitigate the negative of climate change. Adaptation strategies provide an opportunity to address the CC challenges and to sustain the crop production [75].

In the recent year, climate change adaptation has been explored by the farmers in many ways. For example, in Pakistan and Brazil farmers has adapted the climate change variability by adjustment of planting tine and optimization of plant populations [9, 60]. Adjustment of planting date is important to explore the fully potential of crop. High temperature at grain filling stage, reduce the time for grain filling that lead to decrease the yield. Adjusting the planting time with the onset of rains and heat waves would decrease the yield losses. Number of plants per unit area plays a vital role for higher yield in crops especially wheat. The number of productive tillers dies or remains unproductive due to variation in temperature and moisture stress. The optimum plant population compensates the yield loss. The development of improved varieties such as early maturing, drought and heat tolerant are necessary to

Crop (s) name	Region/ country	Adaptation	References
Wheat	Pakistan Brazil	• Use of heat tolerant cultivars • Adjustment of planting dates • Optimum plant population	[9, 81]
Rice	Bangladesh Sri Lanka	• System of rice intensification with alternate wetting and draying • Direct planting	[77, 82]
Maize	Nepal Asia	• Raised bed planting • Early maturing cultivars • Precision nutrient management	[83, 84]
Cotton	Pakistan	• Heat and drought tolerant cultivars • Increase in plant population by 18%	[53]
Sugarcane	Swaziland India	• Ratoon management • Pit planting	[71, 72]
Chickpea	India	• Integrated weed control • Agro-forestry (Wind barrier) • Improved crop varieties (early maturity)	[85–87]

Table 4.
Climate change adaptations for agronomic crops.

sustain the productivity under changing climate. The new cultivars would increase the production per unit area under moisture stress and extreme temperatures [76].

Methane gas is produced form the flooded rice. Flood water in rice blocks the oxygen to penetrate in soil that creates the favorable condition for bacteria that emit the methane gas. So new methods of planting like direct seeded rice and system of rice intensification with Alternate wetting and draying reduce the methane emission and increase the water use efficiency [77].

Precision management of nutrients can increase the resilience in the crops by increasing the efficiency of fertilizers. Precision management of fertilizers in crops especially maize reduced the use of fertilizers that would enhance the production and soil health that lead to decrease the emission of greenhouse gases (GHGs) [78]. Ratoon crop of sugarcane is more adaptive to climatic vulnerabilities. Fuel consumption is less for tillage practices, and less soil is disturbed that lead to reduce the GHGs emission. Pit planting is new evolutionary method in sugarcane. In this methods sugarcane seedling are grown in a small pit under field condition. This method improved the aeration and solar radiation that lead to increase the quality of cane juice and number of canes for milling [79]. Weeds are serious issue in the chickpea cultivation. Weeds compete with the chickpea plants for water and nutrients that reduce the growth and yield of chickpea. So integrated weed control improves the yield. GHGs emissions are also reduced due to less use of synthetic weedicides [80] (**Table 4**).

5. Conclusion

Climate change and variability have negative effects on crop productivity. Change in precipitation pattern, increase in frequency, and intensity of extreme events such as heat waves and drought have detrimental effects on grain yield. Future projections showed that temperature would be increased by 2–3°C at the end of century. Number of hot days and warm night will be increased in Asia and high intense rainfall will occur in summer monsoon. This warming situation would cause a huge reduction in grain yield of crops by end of century. Wheat yield is expected to decrease by 50% in Pakistan, maize yield by 46% in China, cotton yield by 17% in USA and sugarcane yield would reduce by 30% at India. The negative effects of climate change can be mitigated by developing some adaptation measures. The development of heat tolerant cultivars, modification in current production technologies of crop can offset the negative effects of climate change. In future, climate change impacts should be studies by using low and high emission scenarios for early, mid and late century. The adaptation strategies should be quantified based on modeling approaches.

Author details

Ishfaq Ahmed[1*], Asmat Ullah[2], M. Habib ur Rahman[3], Burhan Ahmad[4], Syed Aftab Wajid[5], Ashfaq Ahmad[5] and Shakeel Ahmed[6]

1 Centre for Climate Research and Development (CCRD), COMSATS University Islamabad, Pakistan

2 Ayub Agricultural Research Institute, Faisalabad, Punjab, Pakistan

3 Department of Agronomy, MNS-University of Agriculture, Multan-Pakistan

4 Pakistan Meteorological Department, Islamabad, Pakistan

5 Department of Agronomy, University of Agriculture, Faisalabad, Pakistan

6 Department of Agronomy, Bahauddin Zakariya University, Multan-Pakistan

*Address all correspondence to: ishfaqkanjal@gmail.com

References

[1] Field CB. Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation: Special Report of the Intergovernmental Panel on Climate Change. United Kingdom: Cambridge University Press; 2012

[2] Rezaei EE, Webber H, Gaiser T, Naab J, Ewert F. Heat stress in cereals: Mechanisms and modelling. European Journal of Agronomy. 2015;**64**:98-113

[3] Ullah A, Ahmad A, Khaliq T, Akhtar J. Recognizing production options for pearl millet in Pakistan under changing climate scenarios. Journal of Integrative Agriculture. 2017;**16**(4):762-773

[4] Ahmed I, Rahman MH u, Ahmed S, Hussain J, Ullah A, Judge J. Assessing the impact of climate variability on maize using simulation modeling under semi-arid environment of Punjab, Pakistan. Environmental Science and Pollution Research. 2018;**25**(28):28413-28430

[5] Ullah A, Salehnia N, Kolsoumi S, Ahmad A, Khaliq T. Prediction of effective climate change indicators using statistical downscaling approach and impact assessment on pearl millet (*Pennisetum glaucum* L.) yield through genetic algorithm in Punjab, Pakistan. Ecological Indicators. 2018;**90**:569-576

[6] Lobell DB, Field CB. California perennial crops in a changing climate. Climatic Change. 2011;**109**(1):317-333

[7] Lobell DB, Schlenker W, Costa-Roberts J. Climate trends and global crop production since 1980. Science. 2011;**29**:616-620

[8] Lewis SC, King AD. Evolution of mean, variance and extremes in 21st century temperatures. Weather and Climate Extremes. 2017;**15**:1-10

[9] Ahmad I, Wajid SA, Ahmad A, Cheema MJM, Judge J. Assessing the impact of thermo-temporal changes on the productivity of spring maize under semi-arid environment. International Journal of Agriculture and Biology. 2018;**20**(10):2203-2210

[10] IPCC. Climate Change 2007—The Physical Science Basis: Working Group I Contribution to the Fourth Assessment Report of the IPCC. Vol. 4. United Kingdom: Cambridge University Press; 2007

[11] IPCC. IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, 1535 pp. Cambridge, UK, and New York: Cambridge University Press; 2013

[12] IPCC, "IPCC, 2012: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change," Cambridge University Press, Cambridge, UK, and New York, NY, USA; 2012. Vol. 30, no. 11, pp. 7575-7613

[13] Luo Q, Bellotti W, Williams M, Bryan B. Potential impact of climate change on wheat yield in South Australia. Agricultural and Forest Meteorology. 2005;**132**(3-4):273-285

[14] Valizadeh J, Ziaei SM, Mazloumzadeh SM. Assessing climate change impacts on wheat production (a case study). Journal of the Saudi Society of Agricultural Sciences. 2014;**13**(2):107-115

[15] Lobell DB, Ortiz-Monasterio JI, Asner GP, Matson PA, Naylor RL, Falcon WP. Analysis of wheat yield and climatic trends in Mexico. Field Crops Research. 2005;**94**(2-3):250-256

[16] Yang C, Fraga H, Van Ieperen W, Santos JA. Assessment of irrigated

maize yield response to climate change scenarios in Portugal. Agricultural Water Management. 2017;**184**:178-190

[17] Asseng S et al. Hot spots of wheat yield decline with rising temperatures. Global Change Biology. 2017;**23**(6):2464-2472

[18] Ahmad I, Wajid SA, Ahmad A, Cheema MJM, Judge J. Optimizing irrigation and nitrogen requirements for maize through empirical modeling in semi-arid environment. Environmental Science and Pollution Research. 2019;**26**:1227-1237

[19] Gupta R, Somanathan E, Dey S. Global warming and local air pollution have reduced wheat yields in India. Climatic Change. 2017;**140**(3-4):593-604

[20] Hussain J, Khaliq T, Ahmad A, Akhter J, Asseng S. Wheat responses to climate change and its adaptations: A focus on arid and semi-arid environment. International Journal of Environmental Research. 2018;**12**:1-10

[21] Özdoğan M. Modeling the impacts of climate change on wheat yields in Northwestern Turkey. Agriculture, Ecosystems and Environment. 2011;**141**(1-2):1-12

[22] Aggarwal PK, Mall RK. Climate change and rice yields in diverse agro-environments of India. II. Effect of uncertainties in scenarios and crop models on impact assessment. Climatic Change. 2002;**52**(3):331-343

[23] Naylor RL, Battisti DS, Vimont DJ, Falcon WP, Burke MB. Assessing risks of climate variability and climate change for Indonesian rice agriculture. Proceedings of the National Academy of Sciences. 2007;**104**(19):7752-7757

[24] Saseendran SA, Singh KK, Rathore LS, Singh SV, Sinha SK. Effects of climate change on rice production in the tropical humid climate of Kerala, India. Climatic Change. 2000;**44**(4):495-514

[25] Masutomi Y, Takahashi K, Harasawa H, Matsuoka Y. Impact assessment of climate change on rice production in Asia in comprehensive consideration of process/parameter uncertainty in general circulation models. Agriculture, Ecosystems and Environment. 2009;**131**(3-4):281-291

[26] Bregaglio S et al. Identifying trends and associated uncertainties in potential rice production under climate change in Mediterranean areas. Agricultural and Forest Meteorology. 2017;**237**:219-232

[27] Iizumi T, Yokozawa M, Nishimori M. Probabilistic evaluation of climate change impacts on paddy rice productivity in Japan. Climatic Change. 2011;**107**(3-4):391-415

[28] Khanal U, Wilson C, Hoang V-N, Lee B. Farmers' adaptation to climate change, its determinants and impacts on rice yield in Nepal. Ecological Economics. 2018;**144**:139-147

[29] Srivastava AK, Mboh CM, Zhao G, Gaiser T, Ewert F. Climate change impact under alternate realizations of climate scenarios on maize yield and biomass in Ghana. Agricultural Systems. 2018;**159**:157-174

[30] Rurinda J, Van Wijk MT, Mapfumo P, Descheemaeker K, Supit I, Giller KE. Climate change and maize yield in southern Africa: What can farm management do? Global Change Biology. 2015;**21**(12):4588-4601

[31] Xu H, Twine TE, Girvetz E. Climate change and maize yield in Iowa. PLoS ONE. 2016;**11**(5):e0156083

[32] Araya A, Girma A, Getachew F. Exploring impacts of climate change on maize yield in two contrasting agro-ecologies of Ethiopia. Asian Journal

of Applied Science and Engineering. 2015;**4**(1):26-36

[33] Tong DAI, Jing W, Di HE, Na W, meteorological Bureau J. Modelling the impacts of climate change on spring maize yield in Southwest China using the APSIM model. Resources Science. 2016;**1**:17

[34] Shi W, Tao F. Vulnerability of African maize yield to climate change and variability during 1961-2010. Food Security. 2014;**6**(4):471-481

[35] Xiao D, Tao F. Contributions of cultivar shift, management practice and climate change to maize yield in North China plain in 1981-2009. International Journal of Biometeorology. 2016;**60**(7):1111-1122

[36] Gunn KM et al. Modeled climate change impacts on subirrigated maize relative yield in northwest Ohio. Agricultural Water Management. 2018;**206**:56-66

[37] Cinco TA, de Guzman RG, Hilario FD, Wilson DM. Long-term trends and extremes in observed daily precipitation and near surface air temperature in the Philippines for the period 1951-2010. Atmospheric Research. 2014;**145**:12-26

[38] Emanuel K. Increasing destructiveness of tropical cyclones over the past 30 years. Nature. 2005;**436**(7051):686

[39] Belay A, Recha JW, Woldeamanuel T, Morton JF. Smallholder farmers' adaptation to climate change and determinants of their adaptation decisions in the Central Rift Valley of Ethiopia. Agriculture & Food Security. 2017;**6**(1):24

[40] Liang S et al. Response of crop yield and nitrogen use efficiency for wheat-maize cropping system to future climate change in northern China. Agricultural and Forest Meteorology. 2018;**262**:310-321

[41] Leng G, Huang M. Crop yield response to climate change varies with crop spatial distribution pattern. Scientific Reports. 2017;7(1):1463

[42] Clapp J, Newell P, Brent ZW. The global political economy of climate change, agriculture and food systems. Journal of Peasant Studies. 2018;**45**(1):80-88

[43] Fellmann T et al. Major challenges of integrating agriculture into climate change mitigation policy frameworks. Mitigation and Adaptation Strategies for Global Change. 2018;**23**(3):451-468

[44] Abbas G et al. Quantification the impacts of climate change and crop management on phenology of maize-based cropping system in Punjab, Pakistan. Agricultural and Forest Meteorology. 2017;**247**:42-55

[45] Ahmad S et al. Quantification of the effects of climate warming and crop management on sugarcane phenology. Climate Research. 2016;**71**(1):47-61

[46] Jones MR, Singels A, Ruane AC. Simulated impacts of climate change on water use and yield of irrigated sugarcane in South Africa. Agricultural Systems. 2015;**139**:260-270

[47] Lipper L et al. Climate-smart agriculture for food security. Nature Climate Change. 2014;**4**(12):1068

[48] Chen C, Pang Y, Pan X, Zhang L. Impacts of climate change on cotton yield in China from 1961 to 2010 based on provincial data. Journal of Meteorological Research. 2015;**29**(3):515-524

[49] Adhikari P et al. Simulating future climate change impacts on seed cotton yield in the Texas High Plains using the CSM-CROPGRO-cotton model. Agricultural Water Management. 2016;**164**:317-330

[50] Campbell BM et al. Reducing risks to food security from climate change. Global Food Security. 2016;**11**:34-43

[51] Reddy KR et al. Simulating the impacts of climate change on cotton production in the Mississippi delta. Climate Research. 2002;**22**(3):271-281

[52] Amouzou KA, Naab JB, Lamers JPA, Borgemeister C, Becker M, Vlek PLG. CROPGRO-cotton model for determining climate change impacts on yield, water-and N-use efficiencies of cotton in the dry savanna of West Africa. Agricultural Systems. 2018;**165**:85-96

[53] Rahman MH et al. Multi-model projections of future climate and climate change impacts uncertainty assessment for cotton production in Pakistan. Agricultural and Forest Meteorology. 2018;**253**:94-113

[54] Barlow KM, Christy BP, O'leary GJ, Riffkin PA, Nuttall JG. Simulating the impact of extreme heat and frost events on wheat crop production: A review. Field Crops Research. 2015;**171**:109-119

[55] Meehl Gerald A, et al. Global climate projections. Climate change 2007: The physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. 2007. pp. 747-845

[56] Diarra A, Barbier B, Zongo B, Yacouba H. Impact of climate change on cotton production in Burkina Faso. African Journal of Agricultural Research. 2017;**12**(7):494-501

[57] Lesk C, Rowhani P, Ramankutty N. Influence of extreme weather disasters on global crop production. Nature. 2016;**529**(7584):84

[58] Ewert F et al. Crop modelling for integrated assessment of risk to food production from climate change. Environmental Modelling & Software. 2015;**72**:287-303

[59] Williams A, White N, Mushtaq S, Cockfield G, Power B, Kouadio L. Quantifying the response of cotton production in eastern Australia to climate change. Climatic Change. 2015;**129**(1-2):183-196

[60] Ahmad A, Ashfaq M, Rasul G, Wajid SA, Khaliq T, Rasul F, et al. Impact of climate change on the cotton–wheat cropping system of Pakistan. In: Rosenzweig C, Hillel D, editors. Handbook of Climate Change and Agroecosystems: The Agricultural Model Intercomparison and Improvement Project (AgMIP). ICP Series on Climate Change Impacts, Adaptation, and Mitigation. London: Imperial College Press; 2018. pp. 219-258

[61] Deutsch CA et al. Increase in crop losses to insect pests in a warming climate. Science. 2018;**361**(6405):916-919

[62] Deryng D, Conway D, Ramankutty N, Price J, Warren R. Global crop yield response to extreme heat stress under multiple climate change futures. Environmental Research Letters. 2014;**9**(3):34011

[63] Schlenker W, Lobell DB. Robust negative impacts of climate change on African agriculture. Environmental Research Letters. 2010;**5**(1):14010

[64] Kumar A, Sharma P. Climate change and sugarcane productivity in India: An econometric analysis. Journal of Social and Development Sciences. 2014;**5**(2):111

[65] de Carvalho AL et al. Impact of climate changes on potential sugarcane yield in Pernambuco, northeastern region of Brazil. Renewable Energy. 2015;**78**:26-34

[66] Zhao D, Li Y-R. Climate change and sugarcane production: Potential impact and mitigation strategies. International Journal of Agronomy. 2015;**2015**

[67] Challinor AJ, Watson J, Lobell DB, Howden SM, Smith DR, Chhetri N. A meta-analysis of crop yield under climate change and adaptation. Nature Climate Change. 2014;**4**(4):287

[68] You L, Rosegrant MW, Wood S, Sun D. Impact of growing season temperature on wheat productivity in China. Agricultural and Forest Meteorology. 2009;**149**(6-7):1009-1014

[69] Tao F, Zhang Z. Adaptation of maize production to climate change in North China plain: Quantify the relative contributions of adaptation options. European Journal of Agronomy. 2010;**33**(2):103-116

[70] Marin FR et al. Climate change impacts on sugarcane attainable yield in southern Brazil. Climatic Change. 2013;**117**(1-2):227-239

[71] Knox JW, Díaz JAR, Nixon DJ, Mkhwanazi M. A preliminary assessment of climate change impacts on sugarcane in Swaziland. Agricultural Systems. 2010;**103**(2):63-72

[72] Singh J, Singh AK, Sharma MP, Singh PR, Srivastava AC. Mechanization of sugarcane cultivation in India. Sugar Tech. 2011;**13**(4):310-314

[73] Chavas DR, Izaurralde RC, Thomson AM, Gao X. Long-term climate change impacts on agricultural productivity in eastern China. Agricultural and Forest Meteorology. 2009;**149**(6-7):1118-1128

[74] Smit B, Wandel J. Adaptation, adaptive capacity and vulnerability. Global Environmental Change. 2006;**16**(3):282-292

[75] Fischer G, Shah M, van Velthuizen H. Climate change and agricultural vulnerability. A special report prepared as a contribution to the world summit on sustainable development. Laxenburg, Austria: International Institute for Applied Systems Analysis; 2002

[76] Deressa TT, Hassan RM, Ringler C, Alemu T, Yesuf M. Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia. Global Environmental Change. 2009;**19**(2):248-255

[77] Latif MA, Islam MR, Ali MY, Saleque MA. Validation of the system of rice intensification (SRI) in Bangladesh. Field Crops Research. 2005;**93**(2-3):281-292

[78] Srinivasan A. Handbook of Precision Agriculture: Principles and Applications. USA: CRC Press; 2006

[79] Yadav RL. Enhancing efficiency of fertilizer n use in sugarcane by ring-pit method of planting. Sugar Tech. 2004;**6**(3):169

[80] Pedde KC, Gore AK, Chavan AS. Integrated weed management in chickpea. Indian Journal of Weed Science. 2013;**45**(4):299

[81] Pimentel AJB, Rocha JR d AS, de Souza MA, Ribeiro G, Silva CR, Oliveira ICM. Characterization of heat tolerance in wheat cultivars and effects on production components. Revista Ceres. 2015;**62**(2):191-198

[82] Weerakoon WMW, Mutunayake MMP, Bandara C, Rao AN, Bhandari DC, Ladha JK. Direct-seeded rice culture in Sri Lanka: Lessons from farmers. Field Crops Research. 2011;**121**(1):53-63

[83] CIAT; World Bank; CCAFS and LI-BIRD. Climate-Smart Agriculture in Nepal. CSA Country Profiles for Asia Series. Washington, D.C: International Center for Tropical Agriculture (CIAT); The World

Bank; CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS); Local Initiatives for Biodiversity Research and Development (LI-BIRD); 2017. 26 p

[84] Witt C, Pasuquin JM, Dobermann A. Towards a site-specific nutrient management approach for maize in Asia. Better Crops With Plant Food. 2006;**90**(2):28-31

[85] Ratnam M, Rao AS, Reddy TY. Integrated weed management in chickpea (*Cicer arietinum* L.). Indian Journal of Weed Science. 2011;**43**(1):70-72

[86] Thakur PS, Singh S. Effect of *Morus alba* canopy management on light transmission and performance of *Phaseolus mungo* and *Pisum sativum* under rainfed agroforestry. Indian Journal of Agroforestry. 2002;**4**(1):25-29

[87] Shiyani RL, Joshi PK, Asokan M, Bantilan MCS. Adoption of improved chickpea varieties: KRIBHCO experience in tribal region of Gujarat, India. Agricultural Economics. 2002;**27**(1):33-39