Chapter 6
Field Crops and Climate Change

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Abstract Production of crops and climatic changes are internally linked with each other in several features because changes in climatic conditions are the key reason for abiotic as well as biotic stresses, that have adversative influences on the farming systems at local, regional, and global levels. The yields of major agronomic crops are being negatively impacted by climatic changes in several aspects like disparities in rainfall pattern and intensity, mean temperature, heat waves, changes in weeds infestation, disease causing microorganisms, and pest attack during all growing seasons in major cropping systems. Heat and water shortage stress disturb the crop yield in various ways as response of crop towards these impacts of climatic variables vary. Higher temperature frequently causes a reduction in crop production by reason of the fact that, they generally happen in combination with drought. Crop phenology is negatively affected due to climate change. Yield and yield components are more sensitive under drought condition in comparison to higher temperature in all cropping systems. In this chapter, we summarize the impact of climate change and stresses produced due to climate change on crop production.

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6.1 Introduction

Local and regional climatic circumstances are the most important determinants of agronomic crop productivity (Ahmad et al. 2016; De Pinto et al. 2016; Hatfield et al. 2011) because plant catabolism and anabolism physiological processes are controlled by weather variables like maximum and minimum temperature, solar radiation, carbon dioxide concentration as well as availability of water (Fatima et al. 2020, 2021; Ahmed et al. 2021; Tariq et al. 2021). Agronomic cereal crop production can also be influenced due to climatic extreme conditions, like heat waves, storm, drought, salinity, and flooding circumstances (Ahmad et al. 2019; Porter et al. 2019). Local and regional average and extreme climatic situations are influenced by natural impacts which comprise both external to the global climatic systems (including variations in the Sun's intensity and volcanic eruptions), and internal modes of variability (like the multiyear El-Nino Southern Oscillation system). There are also human influences that affect climatic circumstances at the global, regional, and local level, including the release of greenhouse gases into the environment and human influence that have more limitations of geographical impact, for example, changes in land surface characteristics as a result of agriculture activity (Abbas et al. 2020). During the previous century, but predominantly over the most recent decades in this century, the earth has experienced noteworthy climate change, particularly warming trends in most of the regions worldwide (Pironon et al. 2019). The average air temperature has been enhanced by almost 0.95 °C from 1980 to 2018, and it is predicted to increase to almost 3.0–5.0 °C (depending on various regions) by the end of this century (Kaye and Quemada 2017). In the meantime, global population has considerably enhanced and it is expected that the world will need 70% more food by the mid of this century (Tariq et al. 2018).

Due to an abundant increase in the amount of greenhouse gas levels in the atmosphere, a rapid variability in climate trends in different agricultural regions in the world has been recorded. The increase of CO_2 in the future is raising many questions with respect to food security; the worldwide efficiency of agriculture is also included, whether it will be affected or not. Global yield will be affected by the increasing amount of CO_2, as yield per decade will increase 1.8% (Fig. 6.1). Changes in temperature, cost, and availability of mineral fertilizers, levels of funding for research and development (public or private), atmospheric level of O_3 (ozone) and CO_2 (carbon dioxide), and changes in precipitation regimes are included to affect the agricultural productivity.

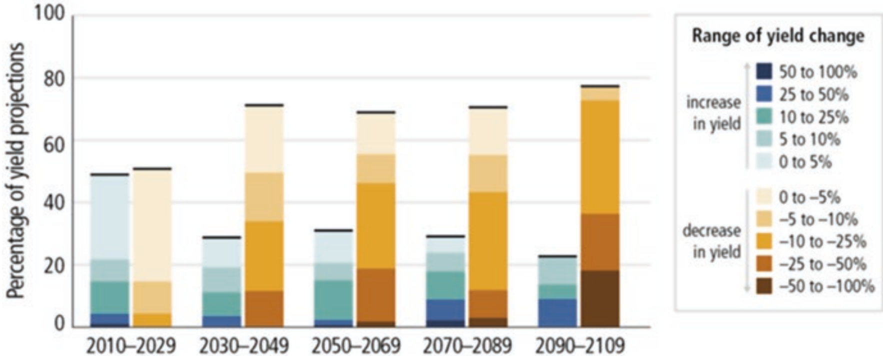

Fig. 6.1 Climate change impact on crop yield

6.2 Crop Response to Global Change

The crop production has been affected and will continue to be effected by the four primary factors:

1. Increase in temperature
2. Increase in CO_2 level
3. Increase in atmospheric O_3
4. Disturbance in hydrological cycle

6.3 Impact on Phenology Change

Phenological stages of the crop plant are set very rigorously to the seasonality of the environment, and therefore are influenced by the changes in the environment. Furthermore, the duration of phenological stages is also associated with CO_2 assimilation, and therefore a shift in the phenology may have effect on crop yields (Ahmad et al. 2017a, b; Abbas et al. 2020). Crop yields are very sensitive to the accumulation of heat units during specific phenological duration, and thus by shifting the phenology, crop yield is also being affected. Several studies reported/projected a reduction in crop yields with climate warming due to shortening of phenological events without considering the management practices (Ahmad et al. 2017a, b; Abbas et al. 2017; Wang et al. 2019; Mousavi-Derazmahalleh et al. 2019).

6.4 Temperature Increase and Crop Yield

Temperature has negative impacts (most likely) on crop yields (Ottman et al. 2012). The major crops which mostly provide 2/3 of the intake of human calories include wheat, maize, rice, and soybean. Assessing the impact of increase in temperature on the growth and productivity of these crops is critical for maintaining food supply globally. Increase in temperature on average decreases the yield and without CO_2 fertilization, genetic improvement, and effective adaptation, reduction in the yield with every degree Celsius increase in temperature is 3.2% by rice, 3.1% by soybean, 7.4% by maize, and 6% by wheat (Zhaoa et al. 2017; Ahmad et al. 2018; Ali et al. 2018a, b; Hammad et al. 2018a; Rahman et al. 2018; Nasim et al. 2018).

To assess the risk of food security and then to develop adaptive strategies to feed the world population, it is necessary to collect the impact of temperature increase on global crop yields; including any spatial variations (Nelson 2010). Wheat production in different countries shows variations towards temperature changes; yield losses for France and the USA were −5.5 to ±4.4% and −6.0 to ±4.2% (per degree Celsius), respectively. With one-degree increase in temperature (global mean temperature) the yield loss would be up to 2.6 ± 3.1% in China (largest wheat producer).

Rice also contributes as a major source of calories in developing countries. Reduction in rice yield with per degree Celsius increase in temperature will be 3.2 to ±3.7 (indicated through analysis of multi method) which is less than wheat and maize. Negative impact of temperature (approximately −6.0% per degree Celsius) was indicated by field warming experiment and grid-point-based simulations but statistical regression suggests no effect. For major rice producing countries, analog differences in estimates between the statistical regressions and other methods are found.

6.5 Climate and Increased CO_2 and O_3 Levels

Rising in the level of CO_2 has been recorded with the start of the industrial era. The concentration of CO_2 was 278 ppm in 1750 and the average increase in its concentration per year is 2 ppm in 2000 (Peters et al. 2011). The increase in CO_2 concentration due to the increasing effect of the industrial revolution is 39% higher than the start with a global average concentration of 390 ppm in 2010. The concentration of O_3 (tropospheric) has also increased due to industrial era from 10–15 ppm to 35 ppm (due to emission of ozone as well). Air pollution has a major contribution and air pollution events can increase concentration to over 100 ppm (Wilkinson et al. 2012). Higher CO_2 concentrations have improved the photosynthesis process in C_3 plants as CO_2 concentration increases fertilization in C_3 crops (wheat, maize, and rice), fruits and vegetable crops (Fig. 6.2). The CO_2 also has a positive effect with respect to water as it plays a vital role in the reduction in stomatal conductance and increased water use efficiency in C_3 and C_4 type crop plants.

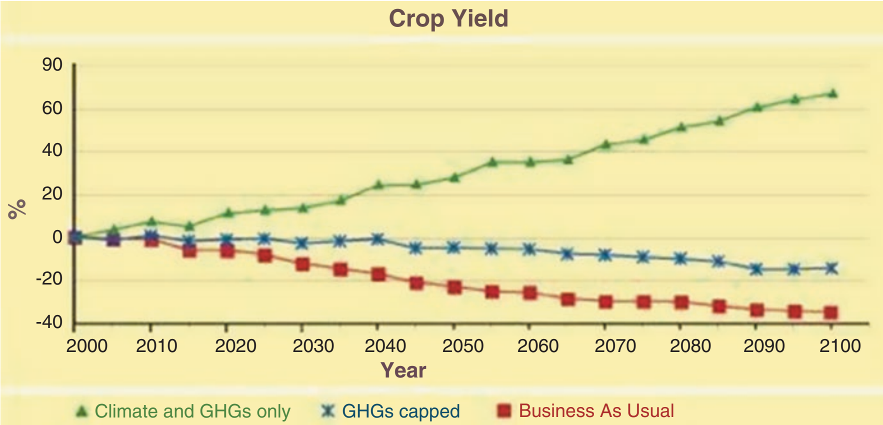

Fig. 6.2 Effect of O_3 and GHGs on crop yield

However, the subject of study also includes the effect of CO_2 concentration which can reduce the nutritional quality of crops (specifically in nutrient poor cropping system) through reduction in protein concentration and nitrate assimilates in harvestable yield (Rahman et al. 2019; Sabagh et al. 2019). Significant fraction of yield growth (loss or gain) of 2–3% is represented per decade (Fig. 6.2).

6.6 Changes in Precipitation Regimes

Precipitation regime has a significant effect on the growth and productivity of crops as 80% of the cropped area is rain-fed where 60% of the world's food is produced. According to the general prediction, the areas with drought will become drier and the areas with high precipitation will receive more precipitation (Liu and Allan 2013). Different soil shows different responses with respect to precipitation regimes. Areas with degraded soil will be greatly affected by seasonal mean precipitation. Water retention will be lower at low moisture potential in the soil with a lower level of organic carbon. Soil with a poor nutrient system recovers slowly from the drought with re-availability of water (Lipiec et al. 2013).

Changes in the precipitation regimes lead to the changes in frequency and length of droughts, changes in the seasonal means, intensity, and timing of individual rainfall events; all these factors are very critical with respect to crop productivity (Fig. 6.3). The effect of rainfall is more vulnerable when it is combined with the temperature changes which ultimately affect the evaporative demand of crops. This problem may lead to the moisture stress of different types with respect to the phonological stage of the crop. It is difficult for the farmers to plan and manage production due to weather patterns and shifting of planting seasons. For example, time

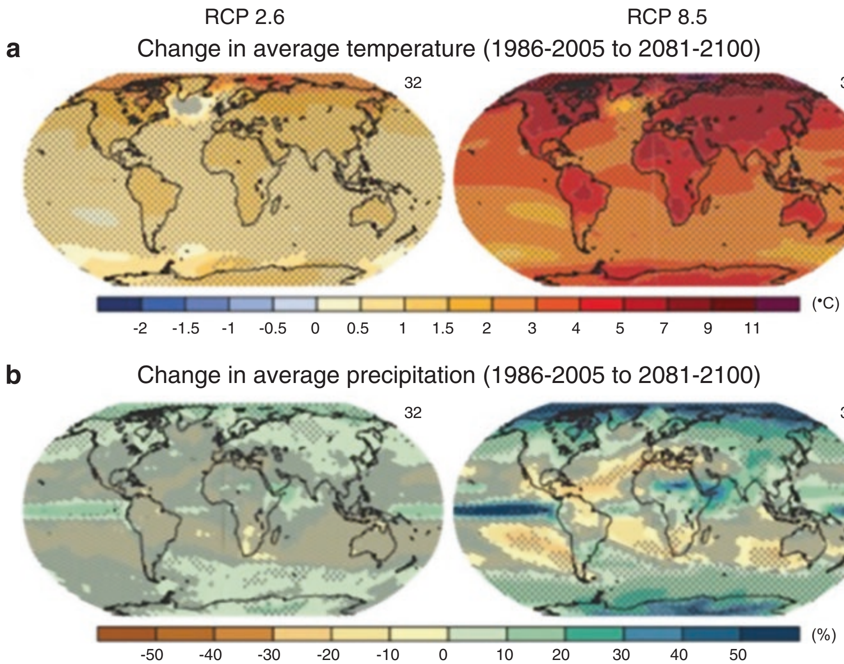

Fig. 6.3 Changes in Temperature and precipitation based on RCP2.6 and RCP8.5 across the world

period of the crop (for completion of growth cycle) is reduced due to late start or earlier end of the rainy season which leads to the reduction in yield.

6.7 Crop Type and Response to Global Change

Various stress factors affect the growth and development of the crop influencing the crop growth linearly or nonlinearly. Crops have different responses towards changes in temperature (Table 6.1) and concentration of CO_2 and O_3 (Fig. 6.4a, b). For example, there is a difference between the crops of different zones as crops of temperate zones include barley and wheat and tropical zones include cassava and sorghum. Average range of temperature has been identified by recent literature as an optimal season average temperature, according to which, for wheat, maize, and soybean, the average temperature is 15 °C, 18 °C, and 22 °C, respectively and for rice and bean (*Phaseolus vulgaris*) suitable temperature is 23 °C and average temperature for cotton and sorghum is 25 °C. Different groups of the crops show different types of responses towards CO_2 sensitivity as C_3 types of plants (grains) are more responsive towards CO_2 as compared to C_4 grains. Root and tuber crops are the most responsive towards it. This can be proved through an example, as with an increase in CO_2 concentration from 385 to 585 ppm, cassava field shows the doubling of dry mass. High

Table 6.1 Climate change impacts on cereals productivity globally and in tropical areas at warming at 1.5 °C and 2 °C beyond the preindustrial levels over the twenty first century

	Increase or decrease in cereal productivity			
	Global		Tropical	
Crops	1.5 °C	2 °C	1.5 °C	2 °C
Wheat (*Triticum aestivum*)	2 (−6 to +17)	0 (−8 to +21)	−9 (−25 to +12)	−16 (−42 to +14)
Maize (*Zea mays*)	−1 (−26 to +8)	−6 (−38 to +2)	−3 (−16 to +2)	−6 (−19 to +2)
Rice (*Oryza sativa*)	7 (−17 to +24)	7 (−14 to +27)	6 (0 to +20)	6 (0 to +24)
Soybean (*Glycine max*)	7 (−3 to +28)	1 (−12 to +34)	6 (−3 to +23)	7 (−5 to +27)

Source: Modified and adapted from Schleussner et al. (2016)

sensitivity can be recorded with high input system (sufficient fertilizer) given that there is no stress of other limiting factors (Ali et al. 2018a, b; Akram et al. 2019; Danish et al. 2019; Iqbal et al. 2019). While, with a high input system, fertilization of CO_2 in C_3 plant will be better with nutritional quality management ().

Increase in CO_2 is helpful for biomass production in areas having drought, but has a drawback of reduction in protein level with high CO_2 level along with no nitrogen inputs into the system (Hammad et al. 2018b; Tariq et al. 2018). Under normal conditions, C_4 plants do not have any benefits from CO_2 level as C_4 plants are capable to increase CO_2 concentration without photosynthesis process. So, C_4 plants will have the lowest reduction in yield under water stress conditions due to less moisture loss (Simpson 2017). The type of damage to crops and seeds will depend upon temperature, and type of plant, developmental stage, and capability to adapt. Highest temperature (above 30 °C) can do permanent damage to plants and seed in storage can also be affected by the temperature above 37 °C (Wahid et al. 2007). The increase in temperature above the threshold level is frequently recorded for maize, wheat, and rice and is predicted to increase worldwide as the climate changes (Gourdji et al. 2013; Amin et al. 2017; Jabran et al. 2017).

6.8 Impact on Pest Infestation

Pests are also influenced by climate change because the body temperature of the pests varies with the temperature of the surrounding and they start moving towards the higher elevations or pole wards (Bebber et al. 2013). Major insect pests of vegetables, fruit crops, pulses, and cereals include pod borers (*Helicoverpa, Spodoptera, and Maruca spp.*), cereal stem borers (*Sesamia, Chilo,* and *Scirpophaga spp.*), whiteflies, and aphids which might travel to temperate areas as changes in cropping patterns are associated with climate change (Sharma 2014). The extent of crop losses will depend on insect biotypes, changes in herbivore-plant interactions, the dynamics of the insect population, species extinctions and the alterations in the

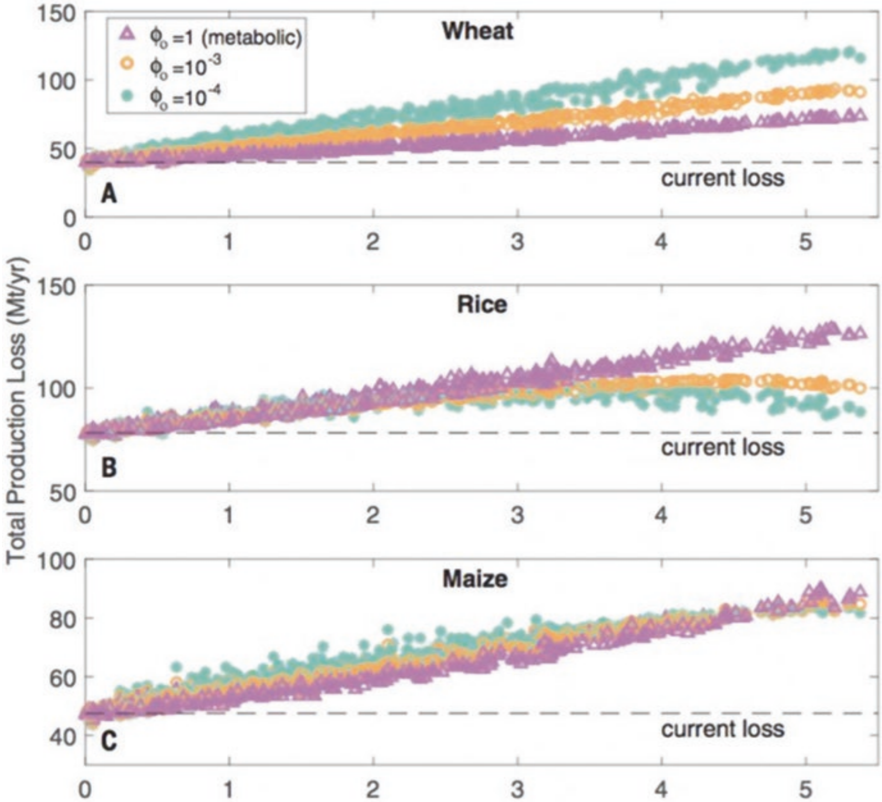

Fig. 6.4 (**a**) Effect of climate change on production of major crops (wheat, rice, and maize). (**b**) Climate change impacts on primary cereals productivity across regions by 2050. *WLD* World, *EAP* East Asia and the Pacific, *EUR* Europe, *FSU* Former Soviet Union, *LAC* Latin America and the Caribbean, *MEN* Middle East and North Africa, *NAM* North America, *SAS* South Asia, *SSA* Sub-Saharan Africa, *NoCC* No climate change, *RCP* Representative Concentration Pathways. **Notes:** Cereals refer to area-weighted average for the following crops: barley, maize, millet, rice, sorghum, wheat, and other cereals

diversity and abundance of arthropods, and the efficacy of crop protection technologies.

6.9 Conclusion

Climatic change is seriously disturbing the farming systems through decreasing production of crops and their products at local, regional, and global levels. Rapid enhancement of concentrations of greenhouse gases are causes of increasing thermal trend, which eventually disrupts the global ecosystem. Overall, in the world,

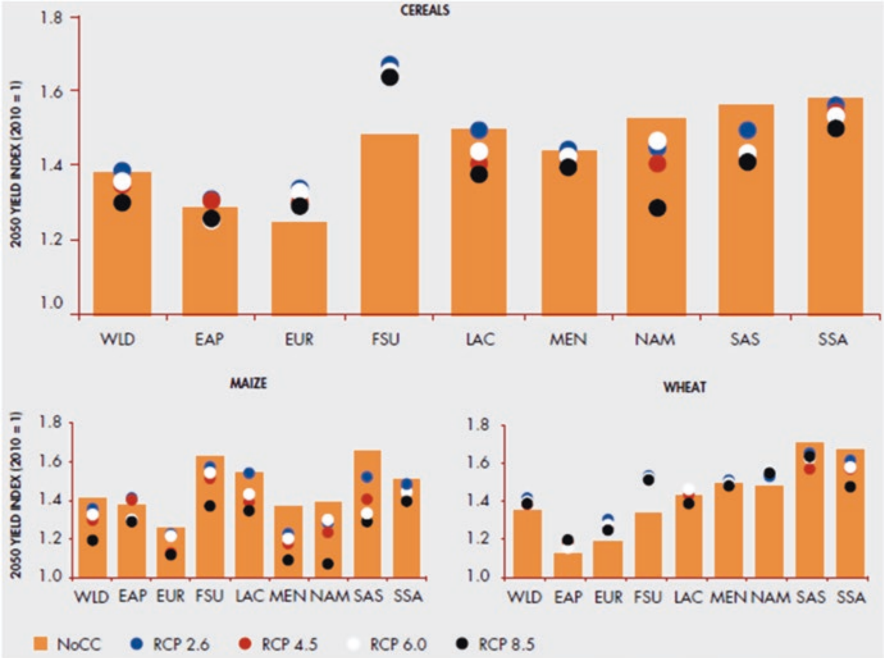

Fig. 6.4 (continued)

climate changes have overwhelming influences on phenological stages and phases, growth, yield attributes, and ultimately crop production in all the farming systems. Climate warming is a major abiotic stress on crops. Abiotic stresses are the foremost category of stresses that crop plants suffer significantly. Major crop yield will be affected more negatively in future scenarios without adaptation strategies. In future, climate change impacts should be studied by using low and high emission scenarios for early, mid, and late centuries. The adaptation strategies should be quantified based on modeling approaches.

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