Chapter

Climate Change and Its Consequences in Agriculture

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Abstract

The process of global warming over the past two centuries has become a major and challenging topic among researchers and policymakers at the international level. The process of global warming has accelerated following the increase in greenhouse gas emissions due to excessive consumption of fossil fuels after the Industrial Revolution of the eighteenth century. The growing trend of the population due to scientific advances in the field of medical sciences, rising levels of education, and health among human societies have had a tremendous impact on reducing mortality and increasing the global population. Consumerism and diversity in consumption patterns among human societies have caused more pressure on the earth's natural resources and excessive use of fossil fuels for industrial production, which has exacerbated pollution and increased greenhouse gases, especially carbon dioxide has led. Global warming can have undesirable consequences in various fields, including agriculture, water resources, plant and animal life, and biodiversity. This chapter deals with the consequences and effects of global warming on agricultural climate indicators. Finally, some agricultural adaptation strategies with these changes are presented.

Keywords: climate change, agriculture, global warming, green house gases

1. Introduction

Today, the issue of climate change has been considered one of the most controversial problems in the world and has led to the reaction of governments and nations. Climate change is not a new issue, as in the past geological periods it has occurred frequently.

More than 35 types of greenhouse gases are produced by humans, which increases global warming. Perhaps the most important greenhouse gas is CO_2, much of which is due to fossil fuel consumption during the post-industrial revolution in the eighteenth century [1]. Recently, the increase in other greenhouse gases such as (N_2O), (CH_4), (C.F.C) have had the same effect as carbon dioxide effects on increasing the greenhouse effect. Overall, 60% of greenhouse effects have resulted from water vapor, 26% due to carbon dioxide and other gases accounted for 14% of this contribution [2]. **Figure 1** represents the contributions of the most important long-lived greenhouse gases to the increase in global radiative forcing from the pre-industrial era to 2019.

Scientists have found a new chemical threatening the atmosphere that appears to be a long-life greenhouse gas. This chemical - Perfluorotributylamine - is the most effective radiation chemical found to date and was more effective than other chemicals regarding its possible impact on the climate [3].

Asakere quotes Landsberg (1975), climate change occurs when reflected in atmospheric rotation patterns and global and at least regional meteorological

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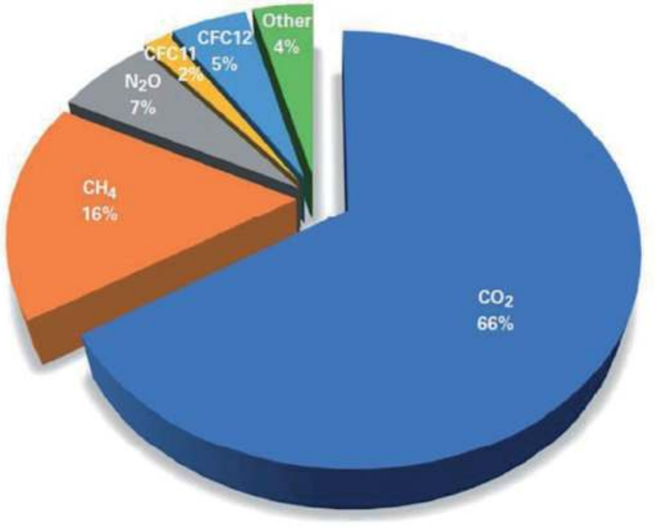

Figure 1.
Contributions of the most important long-lived greenhouse gases to the increase in global radiative forcing from the pre-industrial era to 2019 [3].

processes. He called the temporary deviation that ultimately leads to the return of the previous position or the opposite position as fluctuation. Many atmospheric scientists show little passion to use the term of climate change to explain such alterations. They mainly prefer to use expressions such as variation, long-term climatic variation, climatic anomalies (deviations or anomalies), or climatic fluctuation [4].

The climate in past geological eras: Climate surveys in past geological periods illustrate that important climate change has occurred in the past. Important events of climate change in the past are briefly [2]:

- Earth's climate is constantly changing. Evidence suggests that for most of Earth's history, the climate has been much warmer than today.

- The last glacial period (or ice age) began about 2.5 million years ago. Glacial periods are interrupted by warmer periods called interglacial periods. In North America, continental glaciers reached their maximum thickness and range from about 26,000 to 20,000 years and disappeared completely from North America about 6000 years ago.

- The glacial event called young dryas about 12,000 years ago caused the glaciers to return to north-east America and northern Europe.

- From 1880 to 2012, the earth's surface temperature increased by about 0.85°C. This trend of global warming accelerated in the 1980s and 1990s, then declined in the 2000s.

Figure 2 represents the relative air temperature variations (warmer and cooler periods) during the past 18,000 years. Some regions of the world experienced a cooling and other regions warming that either preceded or lagged behind the temperature variations shown in the diagram [2].

Figure 3 represents that the average temperature variations over the Northern Hemisphere for the last 1000 years relative to the 1961 to 1990 average (zero line). The blue line represents air temperatures constructed from tree rings, corals, ice cores, and pollen. Yearly temperature data measured by thermometers are in

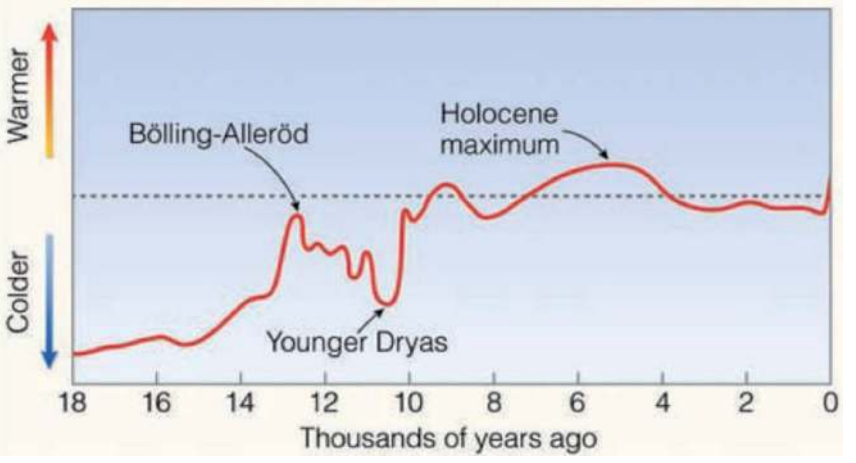

Figure 2.
Relative air temperature variations (warmer and cooler periods) during the past 18,000 years. These data, which represent temperature records compiled from a variety of sources, only give an approximation of temperature changes.

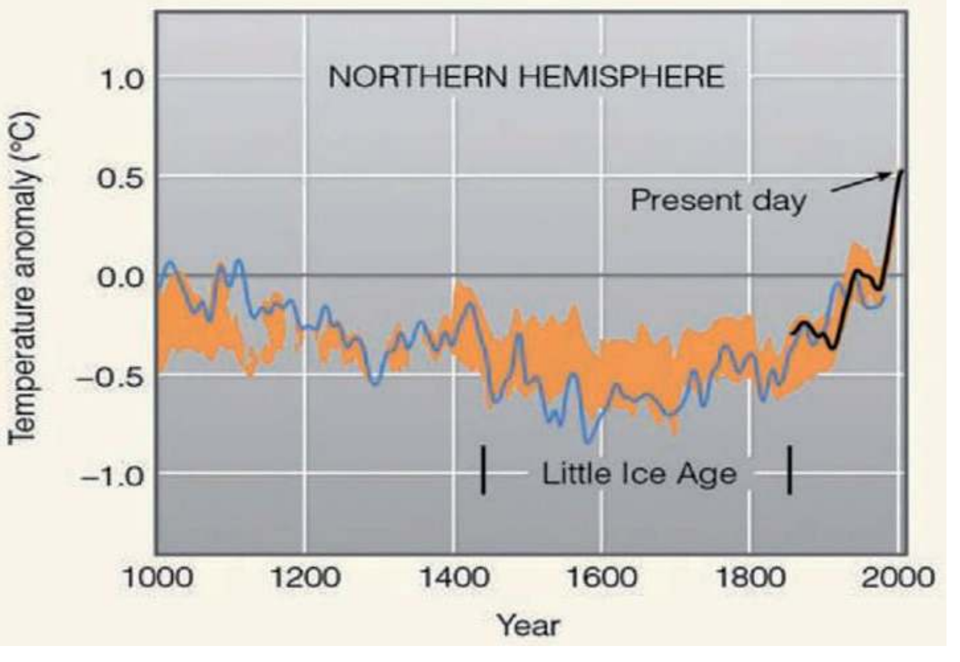

Figure 3.
The average temperature variations over the northern hemisphere for the last 1000 years relative to the 1961 to 1990 average (zero line). (reprinted by permission of the intergovernmental panel on climate change).

black. This reconstruction has been compared to other similar reconstructions. The area shaded orange represents where these reconstructions overlap the data by 50% or more. (Source: Adapted from 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.

2. Possible causes of climate change

The main reasons for this change can be divided into two groups, including the changes caused by natural events and humans [2]:

Climate change caused by natural events: Research shows that climate change occurs under the following conditions.

- External reasons for climate change include (1) changes in incoming solar radiation (2) changes in the composition of the atmosphere, (3) changes in the earth's surface.
- Displacement of continents, along with volcanic and orogenic activities, are the possible causes of natural climate change.
- Milankovic's theory (associated with other natural forces) suggests that intermittent glacial and interglacial periods over the past 2.5 million years are the results of slight changes in the tilting of the Earth's axis and the geometry of the Earth's orbit around the Sun.
- Air bubbles trapped in the ice sheets of Greenland and Antarctica show that CO_2 levels and methane levels were lower in glacial periods and higher in warmer periods interglacial even when the level was higher, it was still much lower than today.
- The amount of fluctuation in the sun's output (brightness) may be for periods of climate change.
- Volcanic eruptions, rich in sulfur, may be responsible for colder periods in the geological past.

3. Climate change caused by human activities (anthropogenic)

Climate change caused by human activities, which has increased especially in the last two centuries, includes:

- Aerosols are injected into the bottom part of the atmosphere.
- Greenhouse gas
- Land Use Changes
- Nuclear War

4. Predicting climate trends based on climate models

Since the Earth's climate system is so large and does not allow controlled experiments, scientists have used mathematical models known as global circulation models (G.C.M.S) to evaluate known processes taking place and their possible interaction. At least ten global atmospheric circulation models have been developed by meteorological scientists in various research groups and used to predict the effects of rising greenhouse gases. The results of these simulations show an increase in average global warming in the range of 3 to 9 degrees Fahrenheit (1.5 to 4.5 degrees Celsius) by the end of the next century [5].

4.1. Weather models predict

- High latitudes and elevated areas experience greater heat continuity than the global average, especially in winter [5].

- Winter and night time temperatures will continue to rise disproportionately.

- The hydrological cycle is likely to be intensified, leading to more floods or droughts.

- Winter rainfall is mostly as rain to reduce snow, snow compaction; subsequently, runoff decreases in spring, and drought intensifies in spring and summer.

- Extreme weather events including very hot spell periods, flash precipitation, and droughts, under increasing conditions of the greenhouse effect, there will be changes in both the average amounts of weather parameters and the frequency of extreme weather events. Carbon dioxide concentrations in the atmosphere will reach twice the current level by 2050. Global temperatures are also expected to warm by 1.6°C. This increase in temperature will result in major changes in the natural and agronomic territory of the world, and some countries will benefit and others will be harmed.

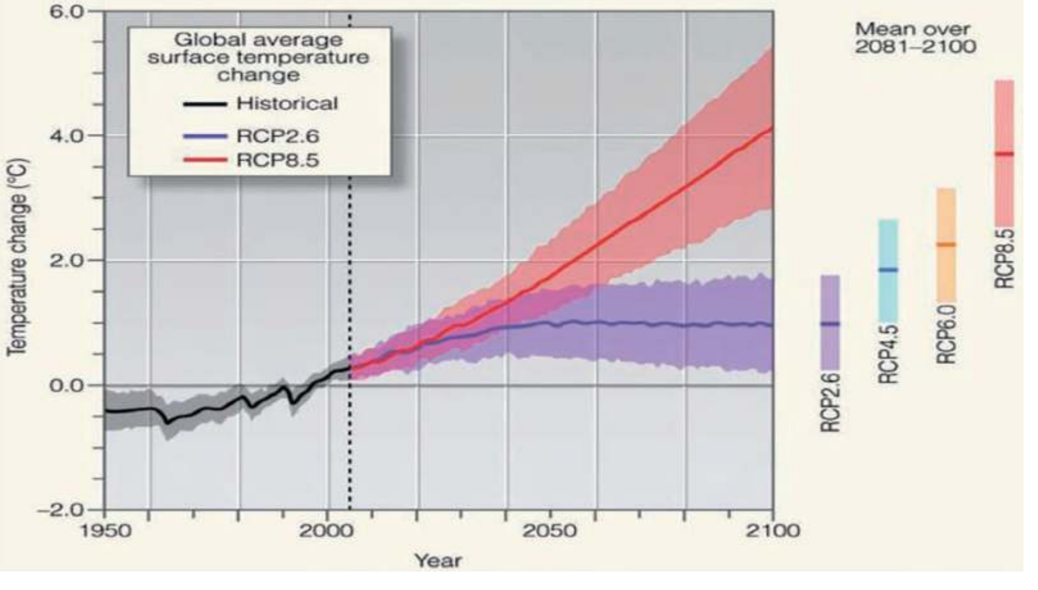

Figure 4.
Global average projected surface air temperature changes (°C) above the 1986–2005 average (dark purple zero line) for the years 2000 to 2100. Temperature changes inside the graph and to the right of the graph are based on dozens of climate models run with different scenarios, based on representative concentration pathways (RCPs). Each scenario describes how the average temperature will change based on different concentrations of greenhouse gases and various forcing agents. The black line shows global temperature change during the twentieth century. The shaded bars on the right side of the figure indicate the likely range of temperature change for each scenario. The thick solid bar within each shaded bar gives the best estimate for temperature change by the years 2081–2100 for each scenario. (see table 18.1 for additional information on the four RCPs.) (source: Adapted from the summary for policymakers, climate change 2013: The physical science basis. Contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change, 2013. Reprinted by permission of the intergovernmental panel on climate change).

The reaction of diseases and pests to climate change can be directly and indirectly. The indirect reaction includes changes in crop type, crop soils, and agricultural operations as well as changes in plant and animal natural habitats that occur after climate change. Thus, changes will occur based on the resources required for pathogens and pests [6].

Under the 2015 Paris Agreement, countries agreed to reduce greenhouse gas emissions to reduce the rate of global average temperature rise to below 2 degrees, above pre-industrialization levels, and attempt to reduce this to 1.5 degrees above industrial levels.

While the overall intention to strengthen the global response to climate change is clear, the Paris Agreement has not specified exactly what the "average global temperature" means, or what period of history should be considered "pre-industrial." To answer the question of how close we are to 1.5 degrees of warming, we must first clarify how both expressions are defined in this special report [7]. The change in global temperature relative to 1850–1900 based on different scenarios (RCP) is shown in **Figure 4**.

Figure 5 represents that human-induced warming in 2017 has reached almost 1 degree Celsius above pre-industrial levels. At the current rate, global temperatures will reach 1.5 degrees Celsius around 2040. The 1.5 degrees Celsius path shown here

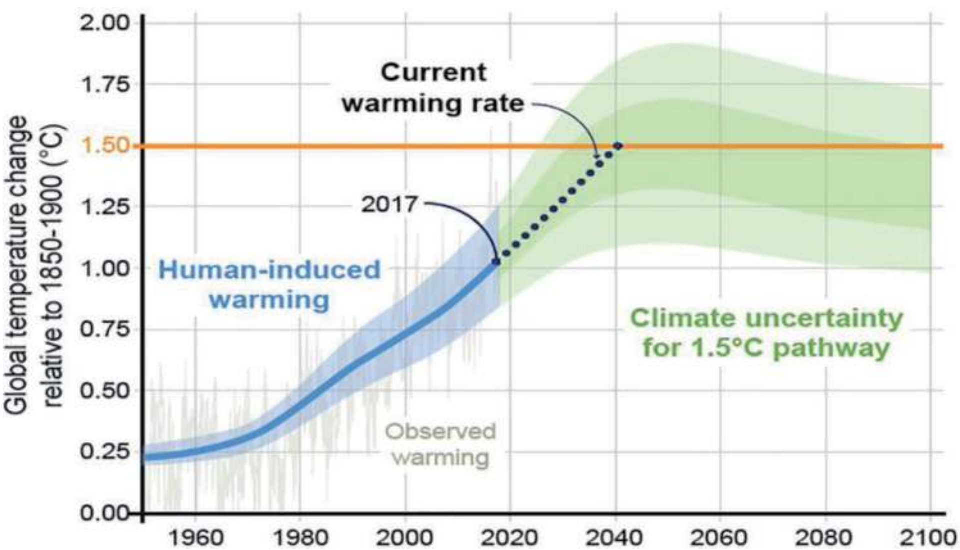

Figure 5.
Human-induced warming and predicting its future trend)IPCC, 2019, P82).

Name of pathway	Likely range of temperature range, °c	Mean estimated temperature change, °c
RCP2.6	0.3–1.7	1.0
RCP4.5	1.1–2.6	1.8
RCP6.0	1.4–3.1	2.2
RCP8.5	2.6–4.8	3.7

**Temperature changes are relative to the average surface air temperature for the period 1986–2005. (Ahrens and Robert, 2014, p. 523).*

Table 1.
Projected average surface air temperature increases: Ranges and best estimates for the period 2081–2100, using six representative concentration pathways (RCPs).*

includes emissions reductions that start immediately and reduce carbon dioxide emissions to zero by 2055 [8]. Each set of simulations uses a different representative concentration pathway (RCP), describing how the total radiant changes over this century (**Table 1**) [2].

5. Consequences and effects of climate change on agricultural climate indicators

Climate change is effective in geographical spread and plant growth in the world. Global warming will cause changes in temperature and humidity conditions in the world. Following that, some possible changes affecting the plant growth process will be mentioned.

6. Consequences and effects of climate change on the temperature characteristics affecting agriculture

The global warming process over the past two centuries, in addition to the effects on the amount of each atmospheric element, can also impact the time of each atmospheric component occurrence during the crop year. Investigation of possible changes in the time series of the onset and endset of 0 and 5°C temperatures and their trend indicates that these changes are global. It is estimated that the minimum temperature increase caused by climate change will increase wheat yields in Australia by 30–50% [9].

Changes in precipitation patterns and rising temperatures may alter land use for food production and consequently cause pathogens or new plant pests [9–11].

Research reveals that overnight temperatures have increased significantly in recent decades [12]. This has caused a decrease in diurnal variation. Naturally, with increasing temperatures during the year, seasonal fluctuations, i.e. the difference between winter and summer temperatures also decrease. Under these conditions, some crops such as sugar beet and sugarcane which react to diurnal variation [13] are affected and this increase in night temperature and decrease in the diurnal variation reduces sugar concentration in those plants.

Research shows that the temperature of winter has increased compared to the past and decreased the intensity of winter frosts [12, 14–17] and the start date of 0°C temperatures have also been postponed, which could have important implications on agricultural production. Roshan et al. [18] to predict the effects of global warming on wheat degree-day changes in Iran, used the general circulation model of INMCM-30 and the P50 scenario, which is the average SERS emission scenario. The results of this study showed that the degree-day values in most climatic regions of Iran have an increasing trend until 2100.

7. Consequences and effects of climate change over the growing season period

Plants, whether natural plants or crops and horticultural plants, to complete their growth and development, need to spend a period with optimum temperature and humidity conditions.

Various definitions and criteria have been proposed to determine the growing season, the first and last frost has been used in many studies [19–22].

The length of the growing season, the length of the days between the last hard frost and the first hard frost in spring are also defined. Hard frost refers to a minimum daily temperature that 50% of plants exposed to it are destroyed [23].

The length of the growing season, the length of time between the last killing frost in spring and the first killing frost in the fall are also defined (U.S. Army Agronomists, 1987). Killing frost is 28°F (−2.2°C) or colder [24].

According to the definition provided by the variation group of the Climatology Commission of the World Meteorological Organization, in the northern hemisphere, the interval between the first period after July 1st (10th of Tir), which is at least 6 consecutive days, the average daily temperature is more than 5°C and the first 6-day period with an average daily temperature of less than 5°C (in autumn) is considered as the growing period. In the southern hemisphere, this interval is considered from January 1st [25].

The length of plant growing season varies not only in terms of each plant species, but also there are differences in one species. Determining the growing season in each region has an effective role in selecting crops and cultivars and determining planting time and other crop decisions.

Many phenological, meteorological, and satellite researches report an increase in the length of the growing season due to rising temperatures in the northern regions during the twentieth century [26].

Chemielewki [27] investigated the relationship between annual and periodic changes of the growing season in Europe with air temperature changes, the results show that in Europe during 1989–1998 with an increase of 0.8°C the average temperature in the last decade, was occurred 8 days earlier at the beginning of the growing season. Research conducted in the United States [28] Australia, China [29], also shows a decrease in the number of freezing days at high and middle latitudes of the northern hemisphere and an increase in the length of the growing period compared to the twentieth century. Regarding the effects of climate change on growing period, researches such as temporal and spatial variation of phenological seasons in Germany from 1951 to 1996 [30], changes in the growing season in the last century [26] can be noted.

One of the important consequences of climate change is the change during the growing season, which follows the change in the beginning and termination of zero temperature and temperature of 5°C (thermal base of cold crops). Changes in the time and length of the growing season may not only have far-reaching consequences for plant and animal ecosystems, but a steady increase in the length of the growing season may lead to a long-term increase in carbon storage and changes in vegetation cover that may affect the climate system. The decrease in the length of the growing season leads to changes in the cultivation calendar and a decrease in yields of crops that have not yet fully reached their maturity and final growth, while increasing the length of the growing season may provide more opportunities for earlier cultivation, ensuring final growth and maturity, and even the possibility of further harvesting (if water is available) [30].

8. Implications and effects of climate change on the characteristics of effective rainfall in agriculture

Most agricultural activities such as land clearing, planting, and harvesting time need to be informed about the start and end dates of rainfall, rainfall amount, and the length of the growing season [1, 31, 32].

Understanding the variation of precipitation and its trend and the characteristics of the growing season is critical for planning and designing appropriate adaptation strategies at the basin level [33]. Increasing or decreasing rainfall and changes in rainfall distribution will affect water balance and will change the frequency of droughts and floods [34]. Research shows that precipitation and temperature changes are not uniform in all parts of the world and there are temporal and spatial fluctuations in different regions of the world) [35].

The amount of annual precipitation and it's seasonal distribution, as well as changes in the beginning and end date of precipitation in many regions of the world, have changed following the trend of rising temperatures on the planet. Many types of research have been conducted by researchers globally to understand the characteristics of precipitation, indicating that precipitation changes in some places increased and in some others have decreased, including [36–41] can be noted.

Dryland farming is defined as the production of crops without irrigation in semi-arid regions of the world, where annual rainfall is between 250 and 500 mm. The success rate of dryland farming in these regions depends on annual rainfall, appropriate distribution of precipitation during the growing period, start and end date of precipitation. If the date of rainfall delays in autumn, germination of crops, especially cereals, is delayed and this causes other growing stages to begin and end with delay. Under these conditions, the thermal needs of the plant are not provided in the autumn; Therefore, the plant, especially wheat, faces unfavorable conditions in the winter; and eventually, it may be destroyed due to freezing temperatures.

Van de Giessen et al. [42] believe that in West Africa, south of the coast, the start of the precipitation season has shifted forward. Rao et al. [43] believe that this evidence cannot always represent climate change. Other researches in this region did not illustrate a significant trend [44]. Future changes in the tropical rotation pattern may cause seasonal changes and lead to increased uncertainty at the start of the precipitation season [45].

9. Climate change and alters in agro-climatic zoning

According to the prediction of climate models that predict the continuation of more heat than the global average for high latitudes and elevated areas, especially in winter, as well as the increase in winter temperature and night temperature than in the past, certainly growing domains including natural and hand planting will be affected. Also, the changes that have taken place in agroclimatic indices in the world can be effective. New climatic conditions different from previous ones can alter the niche space (Ecological nest) of any living organism and disturb the favorable biological conditions for living organisms, including plants and animals. This change in environmental conditions, especially changing climatic conditions, may not be desirable for plant species. So that, by changing the optimum climatic conditions of the plant, new plant species to replace the previous species. Chamura et al. [46] used climate models and concluded that agro-climatic zones associated with major food crops of corn, sorghum, cassava, and peanuts in Ghana have changed. Research by Tranka et al. [47] indicates the deterioration of agricultural conditions in Ghana. Their results confirm that dryland farming in this country is facing serious risks and there is an increased risk of very undesirable years in many climatic zones of this country, leading to annual variation of crop yields. Ceglar et al. [48] studied the effect of climate change on the displacement of agro-climatic zones in Europe. The gradual warming of the European continent has led to the prolonged growing season, the cumulative increase in active temperatures combined with the events of the extreme hot events. This research, which has been conducted using climatic models and different emission scenarios, shows that much of Europe will be affected by the displacement of climate regions facing the north in the coming decades. In addition, the displacement of agro-climatic zones in Eastern Europe may reach twice the speed observed in the period 1975–2016. Some regions may lose the ability to grow specific crops for the benefit of northern European regions. This index-based assessment shows that the potential benefits of prolonging the thermal growing season in northern and eastern Europe are often unbalanced by the risk of late frost and heatwaves in early spring and summer.

Research reveals that due to the shortening of the growing period or due to lack of thermal requirements, agro-climatic zones have been displaced [49, 50–53]. The movement of vineyards from the main planting areas, i.e. the Mediterranean regions to the central and western regions of Europe, is evidence of this claim.

King et al. [54] indicated that suitable conditions for the degree-day of plant growth will experience a north-facing expansion of up to 1200 kilometers in northern regions by the end of the twenty-first century. The northerly expansion will provide favorable conditions for crop production, along with the relocation of agro-climatic zones to inland and other parts of Europe. Although ecological barriers (such as mountains and lakes) can temporarily stop movement, the speed of movement across the boundaries of climatic zones has a significant impact on the redistribution of ecological communities [55].

10. Climate change and increasing water-use requirement of plants

The physical process of converting liquid water into vapor and entering it into the air is called evaporation. This process is also carried out from the free surface of the water, soil surface, or wet surfaces of the plant. On the contrary, the process of transpiration is called water removal in the form of vapor from the leaves and inside the plant. Practically, the categorizing of transpiration and evaporation in two groups is difficult. Therefore, they are combined and used as evapotranspiration. The sum of evapotranspiration and the water needed for leaching soil is called the water-use requirement of the plant. Since the need for leaching is negligible compared to evapotranspiration, evapotranspiration is also defined as the water-use requirement of the plant [56]. The main factors affecting evapotranspiration depend on climatic elements such as temperature, precipitation, humidity, wind speed, and solar radiation. So, any changes in climatic elements will affect the amount of evapotranspiration and water required by the plant [57]. Due to the changes in climatic elements that have occurred following global warming, it can be expected that the amount of evapotranspiration in different geographical regions can also be changed.

Assessments conducted by various researchers indicate that the occurrence of climate change, evapotranspiration, and water-use requirements of plants will undergo serious changes [58]. Tao et al. [59] by investigating the effect of climate change on reference plant evapotranspiration in China's Xiangjiang basin, under RCP scenarios and using the SDSM model for downscale, concluded that in future periods, the amount of reference plant evapotranspiration will increase under all scenarios and the rate of this increase will vary depending on the region and scenario and the highest incremental rate will be observed under the RCP8.5 scenario..

Heidari Tasheh Kabood and Khoshkhoo [60] predicted future changes of reference evapotranspiration in western Iran based on RCP emission scenarios. They used the FAO-Penman-Monteith method to estimate evapotranspiration, canESM2 global circulation model to simulate climatic conditions, and for downscale of the data in this model, the SDMS method was used. The results showed that in all future periods and under all scenarios for all stations, the mean of reference evapotranspiration in annual scales and for autumn and winter will increase significantly at 0.01 level compared to the base period. In a similar study conducted using the CanESM2 model under RCP2.6, RCP4.5, and RCP8.5 scenarios in Mazandaran province in Iran, the results illustrated that the percentage of changes in evapotranspiration per different months varies from −16.1 to 25.7%. The highest and lowest percentage of reference evapotranspiration changes are in October and March respectively [61].

11. Climate change and its effects on plant pests and diseases

The importance of climate in the growth and development of plant diseases has been known for more than 2000 years. The ancient Greeks (286–370 BC) determined that cereals cultivated in the Highlands had less disease compared to cereals cultivated in low-lying areas [62]. Understanding the history of pests may shed light on possible future trends and strengthen the evidence base of national and international policies on plant conservation. Today, it is widely believed that increased international trade and travel will accelerate the pace of pest arrivals, which is caused by adverse globalization outcomes [63]. There is also the view that climate change may accelerate the establishment of new pests [63].

Increasing CO_2 levels associated with climate change may affect plant distribution, abundance, and yield, pests, and pathogens [64]. Research by Anderson et al. [63] on the origin of new plant, outbreaks showed that 56% of diseases were caused by new pathogens.

Lucke et al. [65] investigated pathogens in four major food crops of wheat, rice, soybeans, and potatoes. The limited data show that depending on the interaction between host and pathogen, the effect will be positive, negative, or neutral. Plant pathogens will have different responses to climate change while the life cycle of some pathogens is limited by rising temperatures, e.g., *Puccinia striiformis* f. sp. Tritici. In addition, other climatic factors such as increased CO_2 may provide more favorable conditions for pathogens such as *Fusarium pseudograminearum*.

Major factors of climate change that are likely to affect the severity and spread of plant diseases are increased CO_2 content, heavy and unseasonal rainfall, increased humidity, drought, hurricanes, and warmer winters [65, 66].

The reaction of diseases and pests to climate change can be directly and indirectly. The indirect reaction includes changes in crop type, crop soils, agricultural operations as well as changes in plant and animal natural habitats that occur after climate change. Thus, there will be changes in the resources needed for pathogens and pests. There are plenty of articles and writings on the interaction between pests, diseases, weeds, and climate change, but many of them are still disputed. Changes during the growing period have unfortunately affected the biological territory and life cycle of living organisms. Increasing the length of the growing season has caused changes in the pattern of bird migration, increased infection induced by insects, and changed the habitat of living organisms. The longer the growing season, the more insects such as locusts will be able to complete their reproductive cycle several times during spring, summer, and autumn. Higher winter temperatures may allow larvae to survive the whole winter in areas where the cold threatened them with death, therefore, this will lead to more infections in the next season [6].

Disproportionate warming of high latitudes and elevated areas in winter and at night can affect plant growth and development can change the geographical distribution pattern of production activities and will change the ecological balance between crops and pests. It is possible that, even without climate change, pest management will face major challenges over the coming decades [5].

Insects react to high temperatures by increasing the rate of growth and development and shortening the time between generations (very high temperatures reduce the lifespan of the insect). Warmer winters reduce insect mortality; consequently, the insect population will increase in the coming seasons. Warmer temperatures occur earlier in spring and cause the pest population to expand during sensitive stages of plant growth and development. Warmer winter temperatures will affect pests that cannot currently spend winter (do overwintering) in high latitudes, but these insects will spend winter in lower latitudes areas; then, migrate to agricultural fields in spring and summer [67].

As higher temperatures lead to longer growing seasons in temperate regions, this will provide an opportunity to increase insect damage. Prolonging the growing season will allow pest insects to create an extra generation and subsequently increase the pest population [67].

As temperatures rise, there will be a shift in the agroclimatic regions towards the pole, whereby many pathogens will spread into new geographic regions, where they will encounter potential new hosts [68].

Climate change can have various effects on natural enemies of pest species. Today, the effects of climate change on different aspects of pests and diseases activity on the plant growth process has been considered by researchers globally. Vector and pathogenic response to climate change, pathogen-host interaction response to climate change, the impact of climate change on host resistance, climate change and disease management, climate change effects on natural enemies agricultural pests, the distribution of plants, hosts and natural enemies, and the coincidence of enemy-hosts are among the topics that have attracted the attention of researchers [69].

12. The effects of climate change on biodiversity

Climate change poses new challenges to protect biodiversity. Species ranges and ecological dynamics are currently responding to recent climate change, and current reserves will not support all species designed to protect them. These problems are exacerbated by other global changes. While reviewing the past 22 years of biodiversity conservation research, Heller et al. [70] attempted to identify potential solutions, agreements, and goals to address climate change. In this study, 524 recommendations from 113 articles were published in 57 different journals and three books were identified and introduced.

Research illustrates that species respond to climate change challenges by moving their Niches space (ecological niche) along three axes of time (phenology), location (territory), and self (physiology). There is relatively little evidence of extinction caused by climate change. Studies prove that habitat destruction poses the greatest global threat to biodiversity over the coming decades [5].

At higher levels of biodiversity, climate can cause changes at the plant community level, predicting that this can affect the integrity of biomes enough. The 1000-year period predicts the displacement of 5–20% of the planet's ecosystems, especially the coniferous forests of temperate (regions, tundra, savannah, and northern forests) [71].

Recent assessments in tropical South America show that a large part of the Amazon rainforest is replaced by tropical savannas [72]. Coral coasts are expected to be threatened and destroyed by warmer and acidification of ocean water [73].

13. Agricultural adaptation to climate change

Climate change will have significant impacts on agricultural production and food security in the future. In the third assessment report, Intergovernmental Panel on Climate Change presented several scenarios and examines their implications for global regions. For Africa, it is predicted that many African countries will face a decline in crop yields, and due to droughts, floods, and other extreme events, there is more pressure on water resources, food security, and human health in these countries.

On the Asian continent, food security of the continent is also threatened in many countries located in arid, tropical, and temperate regions due to heat, water, rising sea levels, floods, droughts, and tropical storms. In Latin America, food security in countries, especially livelihood agriculture, is expected to be at risk. At higher latitudes, prolongation of the growing season and rising temperatures due to climate change will benefit agriculture.

Plants can cope with climatic conditions to some extent, some of them have natural adaptability, such as specific cultivars of rice that blossom in the morning to avoid the destructive effects of higher temperatures late in the day. Fewer studies have been conducted on the potential of plant resistance to high-temperature stress. The highest compatibility of products against environmental stresses has been made possible by humans. There are, fortunately, valuable experiences to deal with adverse weather events such as drought, floods, and salinity among farmer communities. For example, new irrigation methods, water stress and water salinity resistant species, and high-yielding plant species have been proposed.

The International Research Center (CGIAR) is one of the most important advisory groups that offers global experiences in agricultural adaptation to climate change conditions, and countries can share their research efforts with the center. Some compatibility methods are presented in **Table 2** [74].

Response strategy	Some adaptation options
• Use different crops	• Carry out research on new varieties
• Change land topography to improve water uptake and reduce wind erosion	• Subdivide large fields
	• Maintain grass waterways
	• Roughen the land surface
	• Build windbreaks
• Improve water use and availability and control erosion	• Line canals with plastic films
	• Where possible, use brackish water
	• Concentrate irrigation in periods of peak growth
	• Use drip irrigation
• Change farming practices to conserve soil moisture and nutrients, reduce run-off, and control soil erosion	• Mulch stubble and straw
	• Rotate crops
	• Avoid monocropping
	• Use lower planting densities
• Change the timing of farm operations	• Advance sowing dates to offset moisture stress during warm periods

Table 2.
Examples of adaptation options for agriculture.

14. Technologies for adaptation to climate change

The Intergovernmental Panel on Climate Change defines adaptation as compatibility in natural or human systems in response to actual or expected climatic adversity or their effects, which mitigate the damage or take advantage of useful opportunities [74, 75].

Different types of compatibility can be categorized into predicted, autonomous, and planned compatibility. There are several adaptation measures that the agricultural sector can take to tackle climate change in the future.

- Changes in planting date
- Cultivation of different species and plant varieties
- Develop and promote alternative crops
- Development of water-resistant and heat resistant species
- More use of intercropping use
- Use of sustainable fertilizers and tillage methods (improving soil drainage, non-plowing, etc.)
- Improved use of crop residues and weed management
- Further use of water harvesting techniques
- Improved control of pests and diseases for crops
- Implementing new or improved irrigation systems (reducing water leakage, maintaining soil moisture - mulching)
- Animal improvement management (providing shelter and shade, changes in heat-resistant breeds, grazing change, and rangeland rotation)
- Greater use of forestry crops practices
- Management of fire improvement in forests (changing layout status, landscape planning, cleanup underlying plants, insect control through planned burning)
- Development of early warning systems and protective measures for natural disasters (droughts, floods, tropical storms, so on).

15. Conclusion

Global warming has had undesirable effects on plant and animal life on Earth. The process of plant life on Earth is influenced by three natural factors: water, soil, and climate. Among these factors, the role of climatic elements is very important and any deviation from the favorable climatic conditions of the plant can pose serious risks to the plant and endanger plant life. Global Circulation Models (GCMS) predict average global warming in the range of 3 to 9 degrees Fahrenheit (1.5 to 4.5 degrees Celsius) by the end of this century. This increase in the average global temperature can have important consequences and effects on agricultural climate indicators. Research conducted by researchers around the world confirms this subject. In this chapter of the book, the consequences and effects of global warming on agricultural climate indicators are discussed, including the following, which are discussed in detail.

Consequences and effects of climate change on the temperature characteristics affecting agriculture.

- Consequences and effects of climate change over the growing season period.
- Implications and effects of climate change on the characteristics of effective rainfall in agriculture.
- Climate change and alters in agro-climatic zoning.
- Climate change and increasing water-use requirement of plants.
- Climate change and its effects on plant pests and diseases.
- The effects of climate change on biodiversity.

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