# Potential Impacts of Climate Change on the Sustainability of Crop Production: A Case in India

**Kousik Atta, Maksud Hasan Shah, Santanu Kundu, Sk. Md. Ajaharuddin, Subhasis Mondal, Apurba Pal, Akbar Hossain, Kalipada Pramanik, Anjan Hembram, Md. Sharafat Ali, and Chaitanya B. Pande**

**Abstract** One of the biggest environmental problems of the twenty-first century is climate change, which is defined as long-term changes. Climate change is defined as a shift in the climate's state that lasts for at least a few decades and can be detected by changes in the mean or the variable nature of its properties. Water and solar energy, which are required for plant growth, are the natural resource foundation for food production. As a result, climate change can effect agriculture productivity in two ways. Firstly, changes in rainfall/precipitation, temperature, and $CO_2$ levels directly impact plant growth, development, and yield. Secondly, snow melt, irrigation availability, soil organic matter, seasonal droughts and floods, among other factors, may significantly impact agricultural land use. Rainfall controls the availability of water and dictates when to plant. Crop growth is controlled by temperature, while pest and disease incidence is controlled by duration and relative humidity. Photosynthetic productivity is influenced by radiation. Wet and dry spells profoundly impact the physiology of standing crops, resulting in product losses. All of these developments would have a significant impact on India's agricultural production. The

K. Atta (✉)
Faculty of Agriculture Sciences, Institute of Applied Sciences and Humanities, GLA University, Mathura, Uttar Pradesh 281406, India
e-mail: kousikatta1995@gmail.com

M. H. Shah
Department of Agronomy, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia, West Bengal, India
e-mail: maksudhasanshah@gmail.com

S. Kundu
Department of Agronomy, Professor Jayashankar Telangana State Agricultural University, Hydrabad, Telengana, India

Sk. Md. Ajaharuddin
Department of Entomology, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia, West Bengal, India

S. Mondal
Department of Plant Physiology, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia, West Bengal, India



C. B. Pande et al. (eds.), *Climate Change Impacts in India*, Earth and Environmental Sciences Library, https://doi.org/10.1007/978-3-031-42056-6_12

present chapter focuses on the impact of changing climate on India's crop production sustainability.

**Keywords** Climate change · Rainfall · Temperature · Weather · Yield reduction

## 1 Introduction

Climate change is a shift in the climate's statement that may be seen in the structure's flexibility and durability, which can last decades or more. Internal and external causes may contribute to climate change [1]. Changes in solar radiation and volcanoes are external forces that naturally occur and provide diversity in the climate system. Other external changes, such as those induced by human activities in the atmosphere. Food production is reliant on water and sun energy as natural resources. Climate change is a long-term climate change that includes normal temperatures and rainfall. Diversity in weather events results in climate change, this type of change alarms food production, sea-level rise contaminates freshwater reservoirs and increases the risk of catastrophic floods [2].

Climate change defined by how the weather fluctuates yearly, either above or below the long-term value. There is a close relationship between climate and food production [3]. Food production depends on the natural resources of water and solar energy. Therefore, climate change affects agricultural production in two techniques. All of this impact on the crop development and yield due to variations in rain water, and other climate elements [4]. However, modern agriculture uses management techniques, fertilizers, pest control, etc. and increases the yield of food crops. Increasing the use of fertilizers, modern irrigation systems, etc. helps to reduce dependence only on the weather. Therefore, the final product i.e. food items in any one year depends

A. Pal
Horticulture College, Khuntpani, Chaibasa, Birsa Agriculture University, Ranchi, Jharkhand, India

A. Hossain
Department of Agronomy, Bangladesh Wheat and Maize Research Institute, Dinajpur 5200, Bangladesh

K. Pramanik
Associate Professor, Department of Agronomy, Visva-Bharati, Santiniketan, West Bengal, India

A. Hembram
Department of Agronomy, Visva-Bharati, Santiniketan, West Bengal, India

Md. S. Ali
Department of Entomology, Uttar Banga Krishi Viswavidyalaya, Cooch Behar, West Bengal, India

C. B. Pande
Indian Institute of Tropical Meteorology, Pune, India

Institute of Energy Infrastructure, University Tenaga Nasional (UNITEN), Kajang, Malaysia

on a variety of man-made and natural materials [5]. The overall amount of rainfall received every year is a significant factor among all natural factors. Crop productivity is also influenced by differences in rainfall distribution over a year. For example, a single period of heavy rain, such as in 1979, might affect crop production in India by around 17%. There are various indirect effects on crop production. For example, evapotranspiration levels, which are radiation, temperature, air, humidity, and humidity, determine irrigation schedules. Similarly, the temperature and humidity combination determine insect pests and pathogens' growth rate and development. These indirect effects of climate change have great economic power when combined with modern farm management. Including climate and weather information in the management system for better crop production is challenging due to the dynamic and complex interaction between climate and agricultural production systems [4]. Rain, solar radiation, atmospheric temperature, humidity, and air are common components that determine the weather. All of these have their importance for healthy plant life.

## 2 Concept of Climate Change

To understand climate change, first of all, you need to be aware of the differences between climate and climate.

- The temperature, precipitation, humidity, wind, and clouds that we experience in space at a specific time and location are referred to as weather.
- The average weather in the area over a lengthy period (30–50 years) is called climate.
- Climate change is a shift in the area's typical weather patterns. This could be a change in the amount of rainfall the area receives on a yearly basis, or a change in the mild local temperature for a specific month or season.

## 3 What Causes Climate Change?

Earth's equilibrium changes (the amount of energy from the sun entering the earth (and its atmosphere)—the energy released into the atmosphere is a fundamental cause of climate change). Human activities have added a vast amount of greenhouse gases (GHG) to Earth's atmosphere since Industrial Modernization began 200 years ago. Instead of releasing solar energy and heat back into space, these GHGs serve as heat sinks (or blankets or car windows) to absorb it. High temperatures shut down when GHG levels are too high, and global temperatures climb beyond the range of natural changeability. There are a variety of GHGs, each with a unique ability to trap heat (known as "global warming") and play a unique role in space life. Because many GHGs have extra consequences, particularly on human well-being, they are frequently referred to as "climate active pollutants" [6].

Carbon dioxide ($CO_2$) is a GHG that causes global warming. Combined, those three processes produce more than 80% of the $CO_2$ emissions that go into the atmosphere [7]. Some other important GHGs include methane, nitrous oxide, carbon black, and other fluorinated gases. These gases emit less $CO_2$, but they also absorb more heat from the environment than $CO_2$. The capacity to absorb heat is measured by the potential for global warming (GWP). $CO_2$, like most prevalent and plentiful greenhouse gases, has a GWP of 1, hence it is used to compare all other GHG warming potential. Climate change, which humans mainly cause, has piqued the interest of all agronomists in recent years. $CO_2$ is required for green plant growth. The high $CO_2$ content in the atmosphere will boost photosynthetic processes, crop growth, and agricultural production without raising crop transpiration water demands [8].

On the contrary, expected climate warming could negatively affect agriculture, partially antagonistic to the positive direct greenhouse gas effects. Models predict that the world temperature can rise by 1–3.5 °C by 2100. Forests, deserts, rangelands, sand, and other untapped ecosystems could face new climatic disorders. Consequently, some flora and fauna species can face extinction. Different elements of the planet can face different types of effects (detrimental or beneficial) of temperature change. Studies of the ascertained changes in surfaces temperature over the Indian region are reviewed by Pant et al. [9]. The all-India mean annual surface temperature derived from seventy-three stations across India shows vital warming of 0.4 °C per hundred years, equivalent to the world mean trend of 0.3 °C per hundred years [10]. This increase is due to the contribution of the post-monsoon and winter seasons, there is hardly any trend within the monsoon season temperature. Of the seventy-three stations accustomed to derive the all India average, thirty stations show a big warming trend whereas six show a cooling trend. A comparison of the trends in rainfall and temperature within the belt north of 20 on wherever most models predict a rise shows that the eastern sector exhibits a decreasing trend whereas the western an increasing one, though neither is significant at the majority of the stations.

Crop yields are generally affected by changes in rainfall, greenhouse gas $CO_2$ concentration, and temperature. Increased rainfall and $CO_2$ concentrations normally result in an increase in yield, while in the tropics, the impact of rising temperatures is frequently the opposite. As a result, if both rainfall and temperature rise, it's vital to determine if the impact of higher rainfall and $CO_2$ can outweigh the impact of increased temperature and evapotranspiration over certain locations and crops.

## 4 Why Short-Lived Climate Pollutants Matter

Impacts of the SLCP occurred shortly, whereas the total impacts from greenhouse gas are going to be undergone later. We must always try for carbon-free transportation and energy systems, to keep the environment, suitable for human habitation. On the other hand, reduced emissions of short-lived climatic pollutants could "buy time" while we work to make the shift.

Reducing global SLCP levels significantly by 2030 will:

- Decrease the global rate of sea-level rise by 20% by 2050
- Cut global warming in half, by 2050, or 0.6 °C, and by 1.4 °C by 2100
- 2.4 million premature deaths globally every year are going to be Checked
- Recover health, particularly for deprived communities
- Many methods to cut back SLCP even have immediate health advantages, such as:
  - Reduce hospitalization related to air pollution
  - Promotion of meat consumption reduction
  - Strict emission restrictions, particularly for diesel cars
  - Clean household stoves in developing countries.

## 5 Five Critical Global Environmental Changes Due to Climate Change

### *5.1 Increasing Temperature of the Earth's Surface and the Oceans*

Since 1957, the globe has been warming at a pace of 0.13 °C per decade, nearly twice as fast as the rate of temperature rise over the previous century.

### *5.2 Alterations in the Global Water Cycle ('Hydrologic' Cycle)*

Over the last 100 years, there have been shifts in total annual rainfall across the country, with some places facing extended drought and others seeing an increase in yearly rainfall. Storms become more frequent and intense as the atmosphere warms and can hold more water vapour.

### *5.3 Declining Glaciers and Snowpack*

Around the globe, nearly every glacier is melting and falling in size, volume, and size. Billions of people depend on glaciers and meltwater is thus crushed.

### 5.4 Sea Level Rise

Warmer waters expand, increasing the volume of water in the sea, causing sea-level rise. Sea-level rise is also influenced by melting glaciers and tropical ice.

### 5.5 Ocean Acidification

The oceans absorb about 25% of $CO_2$ into the atmosphere, resulting in acidic saltwater.

## 6 Potential Impacts of Climate Change on Agriculture in India

Agriculture is the sole source of income for half of India's population. Agriculture and related industries make for 15.4% of India's GDP [11]. Farming techniques include choosing a crop suited to the climate, soil type, and available resources, among other factors. As a result, agriculture and production are completely reliant on climatic circumstances [12, 13]. Temperature, rainfall, and sun radiation all impact the agricultural ecosystem, including the livestock, agriculture, and hydrological sectors. According to an international assessment, crop production would decline by 10–40% by 2100 (https://icar.org.in/node/1738). Around 70% of the population of South Asia still lives in pastoral areas, and 75% of them are poor [14]. Improving agricultural output is critical for ensuring food security and national security, particularly for the poorest people, such as small and medium-scale farmers.

Depending on local climate change and weather variability, land use, and management, the consequences of ecological change on crop productivity might be progressive or devastating. It is important to remember that the region's sustainability in terms of crop production, as well as agronomic processes mitigating impacts and other ecosystem services such as soil protection, cleaning, and recycling of water, is important for biodiversity conservation. Climate change and agriculture are interdependent processes, both occurring around the world. Agriculture is at risk of climate change. High temperatures often reduce crop yields; may increase the spread of weeds and pests. Changes in rainfall patterns make it possible for temporary crop failures and to reduce crop production over the long term. Overall, the consequences of climate change on agriculture are likely to be unfavourable, posing a danger to global food security. Climate change will induce crop failure on the most essential crops in underdeveloped countries. The majority of the population in South Asia will be affected. Climate change will affect irrigation crops in all regions, but irrigated crops in South Asia will decline dramatically. The most significant crops—rice, wheat, maize, and soybeans—will increase as a result of climate change. High feed prices contribute to high meat prices, while climate change is expected to slow meat growth. In India, the effects of climate change on agriculture are being further exacerbated by previously thought, especially wheat if a 1 °C temperature rises in areas such as Punjab, UP, and Haryana could be a loss of about several million tons annually, in addition, production from crops such as rice, sorghum, maize can be reduced by up to 10%. Yield reduction may be due to a reduction in the growing season, a decrease in water availability when water is not harvested properly. Climate change impacts biodiversity, which in turn impacts agricultural production, which is especially crucial for small and medium-sized farmers in India. Poor people, particularly those living in low-productivity agricultural areas, rely mostly on a range of natural genes.

Climate variation has a greater impact on local climate change than it does on global climate change. Since 1880, the average worldwide temperature has climbed 0.83 °C. As a result, any evaluation should be carried out independently by identifying each place. It's also worth noting that not all effects of climate change are negative; knowing the possible favourable benefits of $CO_2$ on plant development and enhancing water usage efficiency can have positive effects on the crop.

## 7 Projected Impact of Climate Change on Indian Agriculture

When $CO_2$ levels rise to 550 ppm, rice, wheat, legumes, and oilseed yields increase by 10–20%.

Wheat, soybeans, and mustard [*Brassica juncea* (L) Czernj. Cosson], nuts (*Arachis hypogaea* L) and potatoes (*Solanum tuberosum* L) yields may be reduced by 3–7% if the temperature is raised by 1 °C.

Most agricultural productivity will decline slightly by 2020, but by 10–40% by 2100.

Important impact on the food quality of basmati rice–wheat etc.

Perhaps some improvement in the harvest of chickpea (Cicer arietinum L), winter (Rabi) Maize, sorghum [*Sorghum bicolor* (L) Moench], and barley and coconut (*Cocos nucifera* L.) on the west coast.

Reduced initial damage has resulted in little losses of potatoes, mustard, and vegetables in northwest India.

Droughts and floods are expected to worsen, causing production swings.

Significant effects on microbes, viruses, and insects.

Fish spawning, migration, and harvesting are anticipated to be affected by rising sea and river water temperatures.

Increasing the amount of water, housing, and energy that animals require.

Heat stress in animals; consequences for reproduction.

Inequality in the food trade as a result of favourable effects on Europe and North America but negative ones on us.

## 8 Effect of Climate Change on Crop Production

Increased $CO_2$ levels aid the growth and output of $C_3$ plants in the atmosphere. On the other hand, increased temperature can shorten plant duration, increase plant respiration rate, influence plant–insect balance, accelerate nutrient mineralization in the soil, lower fertiliser efficiency, and increase evapotranspiration things. All of this can significantly affect crop yields over a long period. Increased $CO_2$ levels are projected to result in increased crop yields and, as a result, will aid in mitigating the detrimental consequences of future global warming. The effects of climate change will alter crop production areas on a worldwide scale. Global warming will lengthen the growing season in medium to high temperatures, allowing for early spring planting, ripening, and harvesting and the ability to complete two more harvest cycles simultaneously. Reduced production in hot locations due to heat tension; damage to crops, soil erosion, and the ability to cultivate land due to heavy rains; and land degradation due to increasing drought are all potential implications of climate change on agriculture. Crop simulation models, influenced by future weather patterns derived from global circulation models, imply that diminishing agricultural production would be exacerbated in tropical regions, where food supply is still scarce.

Although certain benefits may be dependent on crop and regional growth, the overall impact on agriculture is projected to be negative, posing a danger to global food security. Crop-to-crop variations exist. Cotton, for example, can withstand extreme heat and dryness thanks to its vertical taproots. It is, nevertheless, extremely sensitive to water supply, particularly during flowering and wall development. Rising temperatures favor the growth of cotton plants at temperatures exceeding 32. A moderate increase in air $CO_2$ and favor the development of Cotton plants [15]. Generally, the grain cereals will be severely affected. According to Aggarwal [16], a 1 °C increase in air temperature and a 1 °C increase in $CO_2$ concentration can result in a very minor decline in wheat yield in India. Adaptability measures like shifting planting dates and cultivars are also acceptable. However, if no adaptive mechanism is implemented, wheat production loss might reach 6 million tonnes. A further increase in 5C could result in a loss of up to 27.5 million tonnes of wheat production. Rice yields can be lowered by 6% for every 1 °C increase in temperature [17]. However, this is not the same as pulses. They are left to compete with the input responsive cereals. In addition, pulses are heavily planted under marginal lands. Although the severity of abiotic and biotic pressure is stronger in this fragile and lowly productive soil, there are claims that climate change will have a minor impact on legumes due to increased nitrogen fixation linked with higher $CO_2$ levels [18]. Plants that produce oil will have the same impact. Pests and diseases that are emerging as a result of life-threatening weather will have a terrible impact on output.

Most cereal productivity would suffer as a result of rising temperatures and decreasing water availability, particularly in the Indo Gangetic plain. The consequences and sensitivity to climate change differ depending on the code's model. Rice is sensitive to extreme temperatures during pollination, while cotton is sensitive to hot temperatures during the advancement of the boll. Wheat and small grains are responsive to the least event occurring, cold snap throughout flowering and water stress; soybeans are susceptible to water stress and extremely temperatures; and rice is vulnerable to high temperature changes during pollination. Even with the favourable effect of increasing $CO_2$ in the future, severe water shortages mixed with heat stress could have a negative impact on wheat and rice output in India.

### *8.1 Climate Change Effects on Photos, Thesis, $C_3$, and $C_4$ Plants*

Weather conditions have a direct and indirect impact on photosynthesis. Although light absorption is temperature independent, the subsequent stages in converting light to chemical energy react to temperatures in a variety of ways. Increasing $CO_2$ may enhance the process of photosynthesis especially in $C_3$ plants. This may increase in high temperatures and under conditions of water stress. $C_4$ plants do not respond significantly to $CO_2$ emissions because they have a $CO_2$ concentrating mechanism (PEP carboxylase). Other than $CO_2$, the temperature can affect photosynthesis [19]. However, the rising level of $CO_2$ will not lead to an increase in ecosystem productivity, and any potential increase in production should be considered in the context of the many eco-climate changes expected due to climate change. Changes in mean midnight temperatures, soil nutrient availability, pest survival and distribution, water resources and irrigation availability, spatial and temporal rainfall variability, drought and flood frequency and intensity, and soil erosion, for example, all have direct or indirect effects on yield [20]. Similarly, when atmospheric $CO_2$ levels are high, the rate of transpiration increases [21].

In general, temperature changes significantly affect crop phonology. A 2 °C increase in mean temperature resulted in a significant fall in the grained yield of $C_3$ plants like rice, while yields of wheat, soybean, mustard, peanut, and potato are predicted to reduce by 3–7% for every 1 °C increase in temperature [22]. The decrease may have influenced the phonological patterns in $C_3$ plant production. Despite the unfavourable impacts of high temperatures on leaf photosynthesis, the ideal temperature for photosynthesis net is expected to rise as $CO_2$ emissions rise. $CO_2$ driven increases in agricultural yields are far more likely in warmer than cooler conditions, according to several research.

As a result, global warming may significantly impact net photosynthesis. Temperature is a major determinant of crop distribution and production, with significant implications for physical activity on both a local and a transient scale. On the other hand, temperature responses for individual physiological processes do not always correlate with growth, because the latter is an amalgamation of temperature effects on total metabolism [23].

$CO_2$ is required for plant growth since it is the photosynthesis substrate. $CO_2$ is absorbed by plants through their leaves' stomatal pores. Transpiration occurs at the same time. The essential phenomena of plan productivity are the trade-off between

$CO_2$ gain and water loss [24]. Some plants use $C_4$ carbon fixation to get around this problem. Higher $CO_2$ levels in the atmosphere are projected to improve photosynthetic efficiency and, as a result, the total rate of plant growth in $C_3$ plants. Due to higher levels of $CO_2$ absorption and stronger stomatal resistance to water loss, $C_4$ species, particularly dicots, require less water than $C_3$ species at current $CO_2$ levels [25]. $C_3$ species would be more competitive than $C_4$ species in the event of drought and increased $CO_2$. Low stomatal conduction in $C_4$ plants at any given $CO_2$ level results in a drop in respiratory rate and a higher leaf temperature in $C_4$ plants, hence the higher temperature is linked to the damage to $C_4$ plants in the same location. Given the stronger average promotion of high $CO_2$ growth in $C_3$ species, increased $CO_2$ increases leaf size, which should increase sleep temperature during heat stress more in $C_3$ than $C_4$ habitats.

## *8.2 Climate Exchange Outcomes on Soils*

Organic matter availability, temperature regimes, hydrology, and variations in evapotranspiration capacity are some potential changes in soil growing characteristics that may occur due to global climate change. The effects of climate change on soil properties are numerous. Rainfall quantity, intensity, timing, and type impact soil formation; daily and seasonal temperature fluctuations impact moisture effectiveness, dynamic rates of biological activity and chemical reactions, and vegetation types.

Soil moisture pressure will be driven by stepped evaporation from the topsoil and the plants' rapid transpiration. A changing climate may also affect mineral soil's workability and susceptibility to erosion, compaction, and diminished water retention capacity. In regions with heavier winter rainfall, a few soils may be more susceptible to corrosion. Mini soil physical qualities are derived from a variety of chemical and biological processes, and can be further influenced by weather panorama positions and land use. Soil available water and distribution may also react quickly to climate change, particularly to variable and high-intensity rainfall or drought events, and thus control strategies, such as cover crop planting, conservation tillage, and organic matter incorporation, can be counted on to keep or even improve water infiltration and available water in soil, which can help alleviate the effects of extreme rainfall and drought events.

## *8.3 Climate Change Effect on Insect Pest*

Increased temperatures caused by climate change can have a variety of effects on crop insect populations. The interaction between the insect pest and their host plant is changing as a result of climate change. Global warming additionally changes the flowering time in temperate areas, mainly to the incumbent of latest insects and achieving a pest repute of non-pest insects. This leads to the large pests shifts in due route of time concerning change in the climate.

Added peers of insects in temperate climates due to greater than before temperature might also compel insecticide application to preserve population below the economic damage threshold. $CO_2$ appears to have an indirect effect on bugs, with detrimental effects on insects resulting from changes in the host crop. Exposure to extreme $CO_2$ levels boosts plant photosynthesis, increasing above-ground biomass, leaf area, yield, carbon, and the C:N ratio. These changes may increase the attractiveness of food for herbivorous insects, which may have a variety of effects on insect herbivore performance. The effects of $CO_2$ on nutritional quality and secondary metabolites off the host plant will modify the insect-host plant interaction. Plants are more susceptible to pest damage as a result of both direct and indirect effects of moisture stress, particularly in the early stages of plant growth. A few insects are rain-sensitive, and severe rains kill or eradicate them from vegetation. Drought-stressed tillering cereals diminish the reproductive capability of overwintering aphids, hence lower winter rainfall should result in lower aphid development rates.

### 8.4 Climate Change Effects on Disease

Increases in temperature, UV radiation, and relative humidity may make natural plant products, ento-pathogenic viruses, fungus, bacteria, and nematodes, as well as synthetic pesticides, less effective, with natural plant products suffering the most.

### 8.5 Climate Change Effects on Weeds

Climate change could result in the spread of tropical and subtropical weed species in temperate regions, as well as an increase in the number of temperate weed species that are now hampered by cold temperatures at high latitudes. Alterations in rainfall patterns will lead to variations in water availability, which will lead to weed changes. Species and cultural factors influence drought responses to agricultural circumstances. Any condition that raises the crop's environmental stress may make insects and plants more susceptible to pathogen assault, reducing the crop's capacity to compete with weeds. Rising temperatures substantially impact agriculture in general, crop weed competition in particular, and weed management. It has been suggested that weeds of transient origin are particularly responsive to slight temperature rises, and there have been multiple occurrences of considerable weed growth in response to rising temperatures [26].

# 9 Sector-Wise Effects of Climate Change in Agriculture

## *9.1 Field Crops*

Crop yields in South Asian countries are expected to fall by 30% by the middle of the twenty-first century. Rainfall and temperature variations will have a greater impact on North Indian states and Bangladesh [27]. That is, in India, a 1.50 C increase in temperature and a 2 mm decrease in rainfall reduced paddy yields by 3–15%. [14]. Climate change may cause crop yields and production to differ from region to region. Normal agricultural yields in Pakistan are predicted to fall by 50%, according to the Meteorological Office (the United Kingdom's National Weather Service). Under optimum hydrologic circumstances, corn production in European countries is predicted to increase by 25% (Fig. 1).

## *9.2 Horticulture*

High respiratory damage occurs in vegetable crops as a result of extreme high temperatures caused by climate change. High temperatures during flowering have been shown to significantly impair the fruiting stage of navel oranges (Davies 1986). High temperatures have an effect on the flowers or blossoms of garden plants, which burn,

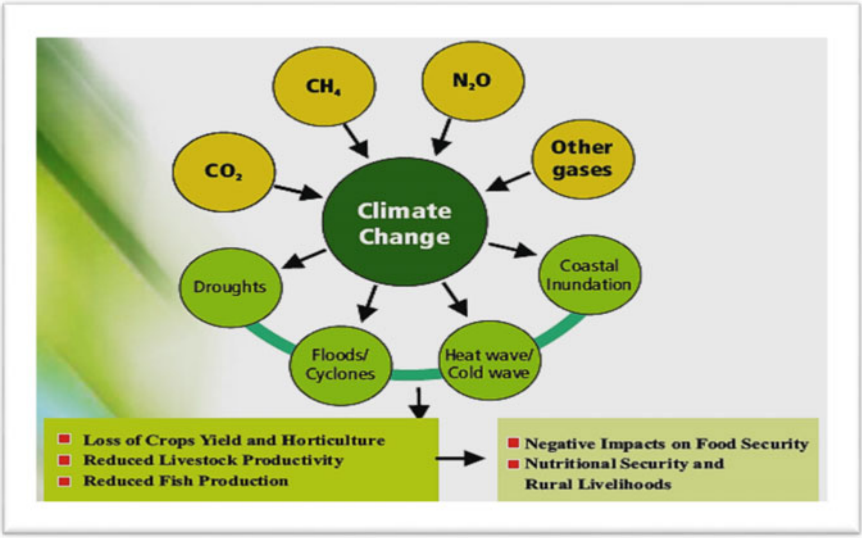


**Fig. 1** Causes and impact of climate change on agriculture and allied sectors (*Source* Srinivasa et al. [28])

as well as fruits and vegetables. In litchi orchards, temperature pressures during the ripening period induce fruit burns and cracks [29]. Lack of moisture causes sunburn and cracking in fruits including cherries, apricots, and apples. Floods have wreaked havoc on most food crops, particularly tomatoes.

### *9.3 Livestock, Poultry and Fishery Sectors*

Climate change has an impact on the productivity, reproduction, health, and adaptability of cattle, poultry, and fisheries. Pereira et al. [30] found that high temperatures cause physiological changes in the body of the animal, such as an increase in respiration rate (>70–80 per minute), blood flow, and body temperature (>102.5° F). Diseases, a lack of seedlings, heat stress, and breeding procedures contribute to Bangladesh's enormous economic losses due to lower cow productivity [31]. Uneven weather variations have a direct impact on animal output by 58% and reproduction by 63.3% [32]. Heat stress is more common in dairy breeds than in meat types. Higher milk producing breeds are more sensitive to heat stress because of increased metabolic heat production, low milk producing animals are more resistant to heat stress because of lower metabolic heat output [33]. Increasing the temperature and temperature-humidity indicator outside the essential threshold level reduces dry matter intake and milk yield. It also has an effect on the animal's physiology [34]. Floods and cyclones wrecked large-scale agricultural production in southern and central Mozambique in 2009–10, resulting in cattle, infrastructure, and food loss [35]. Poultry are particularly vulnerable to temperature-related issues, particularly heat stress. Chronic heat stress causes endocrinological changes in broiler hens that increase lipid buildup, inhibit lipolysis, and induce amino acid catabolism [36].

The amount of poultry consumed will decrease due to heat stress [37], resulting in decreased body weight, reduced egg production and meat quality, reduced egg shell thickness and increased egg breaking rate [38]. Heat stress reduces egg shells' strength, weight, ash content, and thickness [39]. Rising environmental temperatures may boost fish growth and development seasonally, but it increases the risk of the population living outside in the heat tolerance zone [40]. Fish mortality and distribution will be affected by a 1 °C temperature increase [41]. The shift in the mating season of Indian major carp to fish hatcheries in West Bengal and Orissa from June to March was caused by a temperature increase from 0.37 to 0.67 C (DARE/ICAR Annual Report, 2008–09).

### *9.4 Economic Losses of Climate Change in Agriculture*

The agricultural sector is very vulnerable to climate change and is expected to suffer significant economic losses worldwide. According to the United Nations Office for Disaster Risk Reduction (UNISDR), the disaster-affected nations experienced a direct economic loss of US 29 2908 billion from 1998 to 2017. Climate-related disasters are responsible for 77% of all damage. Climate change's effects on agriculture have become more specific in recent years. According to the Economic Survey of the Government of India (2018), climate change has resulted in an annual loss of US $9.9–10 billion.

## 9.5 Agro-techniques for Adaptation to Climate Change

"Adapting to or profiting from environmental or social stimuli in reaction to actual or expected stimuli and their consequences or effects on environmental, social, or economic systems," according to the IPCC [42, 43]. "Possibilities linked with in both the creation and evaluation of impacts and vulnerabilities, as well as response options, adaptation to the climate change debate is critical.

## 9.6 Primary and Secondary Tillage Practices

Planting cover crops and green manure crops can help prevent future loss of soil organic matter, moisture, erosion, and nutrient loss due to climate change. This low-tech agricultural method could also be a viable option.

## 9.7 Choice of Crops and Cultivars

Introduce or select resilient varieties/hybrids/composites for climate change (Fig. 2). Long-season varieties can be selected to provide a stable yield under more variable conditions.

## 9.8 Relocation of Crops in Alternative Areas

The effects of climate change vary across crops and regions. More suitable crops and areas need to be identified and relocated to unsuitable areas for climate change/variability.

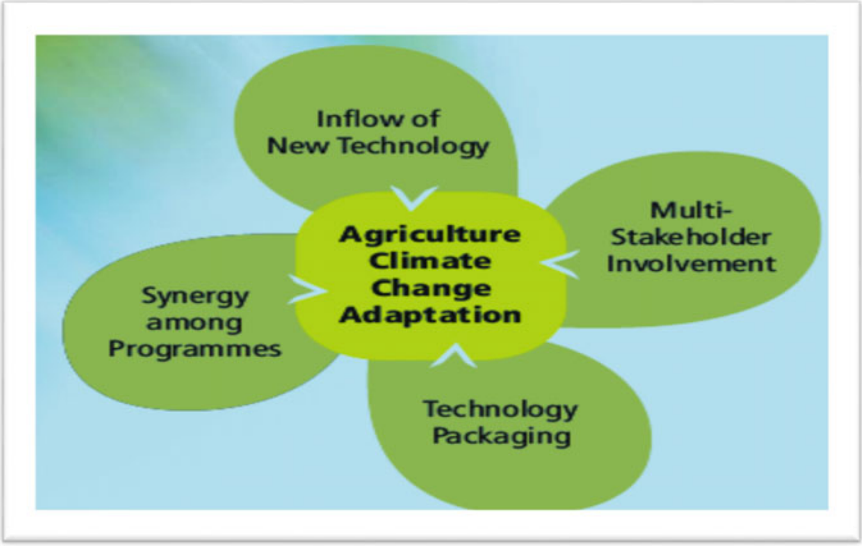


**Fig. 2** Key strategies essential for climate change adaptation in the agriculture sector (*Source* Srinivasa et al. [28])

## 9.9 Resilient Cropping System

The advantages include (a) maintaining and improving soil fertility as crops deplete soil fertility, (b) improved crop growth as crops may provide mutual support to each other, such as reducing lodging, enhancing winter survival, or even acting as windbreaks to enlarge growth, and (c) disease spread reduction. The more plant species there are and the longer it takes before the soil is reseeded with the same crop, the more disease problems are likely to occur (see Fig. 3).

Effective crop-growing season, which is calculated from long-term rainfall data analysis, is used to determine the various cropping systems, including mono-cropping, intercropping, and double-cropping. The All India Coordinated Research Project for Dryland Agriculture (AICRPDA) conducted research on intercropping systems (ICSs) and found that additive series were more successful than replacement series in various seasonal drought situations, with multiple benefits including higher output and returns, spread labour peaks, soil fertility maintenance (with legume inclusion), and production stability. When seasonal rainfall was above normal, optimum production was obtained. When rainfall was normal, relatively high values of land equivalent ratios were achieved; and when rainfall was low, one of the two crops yielded reasonably, giving insurance against weather aberrations [44].

Furthermore, the ICSs have discovered that, due to soil moisture replenishment, the rainy (Kharif) season is more suitable to intercropping than the rabi season in India's wet production systems. Pigeon pea performed better as a foundation crop or intercrop, particularly in intercropping systems based on sorghum, cotton, and pearl


**Fig. 3** Schematic diagram of the overall strategy of climate change adaptation with the implementation of various technological interventions (*Source* Srinivasa et al. [28])

millet [45]. The diversity of cropping systems, which is tied to rain-fed agriculture and influences the socio-economic conditions of the agricultural community, has been one of the most important aspects of Indian agriculture. Double cropping is possible in areas with sufficient rainfall (usually more than 750 mm) and a soil moisture storage capacity of more than 150 mm. Rainwater collected in agricultural ponds for the development of winter crops can also be used for double cropping. One of the two crops could be a 60–70-day crop (generally a legume), while the other could be a 110–120-day crop (usually cereal).

## 9.10 Seed Rates and Spacing

Seed rates and row spacing must be changed to cope with situations such as delayed and early season dryness, which need re-sowing. Plant populations may be modified based on crop water needs and water-use efficiency, which can be seen in early-season rainfall.

## 9.11 Contingency Crop Planning

Contingency crop planning is putting in place a strategy for switching crops or making other decisions based on the current rainfall condition and soil moisture status in a specific area [46]. Due to extended dry spells after seeding at the regular commencement of the monsoon, the crops endure agricultural drought at various stages. During the rainy season (July to September), a seasonal drought causes crop failure. Early-season dryness is most often caused by a delayed beginning of monsoon or a lengthy dry period shortly after the rainy season begins. Mid-season drought is caused by a lack of soil moisture availability between two successive rainfall events during the crop-growing cycle. As the crop matures, so does its impact. At each stage, the length and intensity of the dry situation. Droughts that occur late in the season or towards the end of the monsoon season are more likely to occur in years with a late start or inadequate monsoon activity. The early monsoon withdrawal causes early-season droughts in July, mid-season droughts in August, and terminal droughts in September, all of which have varied consequences on plant growth and output. Contingency crop planning refers to a technique for picking crops based on rainfall and moisture levels during any agricultural growing season.

## *9.12 High Intense Rainfall Events*

Preventing seed germination and collecting produce are two stage-recommended practises throughout the time of crop maturity. In the event of inconvenient rains during the vegetative stage, contingency measures include: draining excess water as soon as possible, applying 20 kg N + 10 kg K/acre (0.4 ha) after draining excess water, applying 50 kg urea + 50 kg mutate of potash (MOP)/acre (0.4 ha) after draining excess water, gap-filling either with accessible nursery or by piercing the tillers from the existing hills in rice, weed control, and appropriate plant.

High intense rainfall events generally occurred due to the following events:

**Floods**: The type of material (sand or silt) deposited during floods has an impact on crop/field management. Early sand exclusion or ploughing in of sand (depending on the degree of deposit) to assist rabi crops or Kharif are examples of ameliorative treatments in sand-deposited agricultural fields/fallows. An early rabi crop strategy is recommended in existing cultivated regions and current fallow lands in the silt deposit Indo-Gangetic plains. Other efforts include emptying stagnant water and bolstering agricultural bunds, among others. In diara (flood-prone land regions), different agricultural plans for receding scenarios are included. Flooding is common in rice-growing areas, resulting in the loss of nurseries as well as the strengthening of include alternate losses of nurseries, delayed transplantation, or damage to previously transplanted fields. To avoid losing the season, community nurseries are recommending boosting scheduled bushenings, transplanting in damaged fields and transplanting new areas, or direct seeding depending on seed availability. Spraying a salt solution on the submerged crop at maturity or on harvested produce to prevent early germination are two further methods.

**Heatwave**: Heat-tolerant cultivars, light, regular watering, foliar spraying with thiourea or $KNO_3$ at appropriate distances, and other interventions are suggested.

**Cold wave**: Cold-tolerant types should be used, light watering should be done often, and smoking should be done at night, among other things.

**Frost**: Frost-tolerant varieties are sought, planting schedules are adjusted to avoid sensitive phases falling during frost periods, young plants are thatched, and ground cover such as shelterbelts and shade trees is employed to reduce heat loss, among other things.

**Cyclones**: In high-risk locations, forestry windbreaks or shelterbelts, as well as the cultivation of storm-resistant crops, are recommended (e.g. ginger and pineapple). Other methods include field drainage, staking and propping of plantation crops, and washing and drying of harvested field crops.

**Hailstorm**: Anti-hail guns and anti-hail nets have been suggested as possible solutions. To prevent further fungal infection, spray 0.1% carbendazim on the affected area.

## 9.13 Nutrient Management

It's unsafe to rely solely on basal soil application of nutrients in arid and semi-arid locations where dry spells and droughts are prevalent. It is preferable to supply roughly 50–60% of the nutrients by a basal application and the rest through a foliar spray. Plants are unable to acquire an appropriate quantity of nutrients when soil moisture is scarce, which has detrimental consequences for their general health, particularly their growth and grain quality. As a result, it is beneficial to provide chosen plants with nutrients, either with or without plant development agents, in order to help stressed plants recover quickly. For example, Pulses, are grown without fertilisers or irrigation under rainfed and rice fallow environments, and their yields are low. Foliar fertiliser treatment can be used to boost their yield. Pulses also have a shorter duration between the maximal vegetative and reproductive stages. Foliar nutrition is a superior technique in the nutritional management of pulses to avoid any of these issues. A foliar spray of 2% diammonium phosphate (DAP) was applied in rainfed and rice fallow pulses.

## 9.14 Weed Management

Another important endeavour is timely weed control. Stale seedbed method, manipulation of sowing time so that ecological conditions for weed seed germination are not favourable, mulching, crop diversification, selection of acceptable crop varieties as well as planting of weed-smothering crops, land levelling, conservation tillage, and efficient weed-management strategies are examples of different types of measures.

## *9.15 Water Management*

Conservation of water for irrigation while drought conditions persist, as well as drainage of excess water from agricultural land during flooding, should be prioritised. To keep water levels in aquifers stable, rainwater harvesting and other water-saving activities should be used. In drought-prone nations and tropical climates, reusing waste water should be encouraged. Because agricultural productivity depends on water availability, advancements in runoff control and irrigation technologies will be critical.

## *9.16 Mitigation Strategies*

Mitigation refers to efforts to reduce or eliminate greenhouse gas emissions. Climate change mitigation is the reduction of human-caused (anthropogenic) greenhouse gas emissions (GHGs). Carbon sink capability can also aid with mitigation, such as through reforestation. The following agro-techniques must be applied to combat climate change.

## *9.17 Crop Management*

Intensively maintained croplands provide several chances to implement strategies that minimize net GHG emissions. The following, partially overlapping types of farmland management mitigation practices: Increased soil carbon storage can be achieved by enhanced agronomic methods that increase yields and create greater carbon residual inputs. These are some examples of unethical behaviour. Improved crop varieties are one example; other farming practises that use less fertiliser can also reduce emissions per hectare. These 'catch' or 'cover' crops offer carbon to soils while also absorbing plant-available Nun used by the preceding crop, minimising $N_2O$ emissions. Methane emissions from rice. Intermittent flooding has been proposed in many studies as a technique to reduce $CH_4$ emissions. In all irrigated rice regions across the country, by transitioning from the current technique of water management to intermittent floods. It is possible that the amount of $CH_4$ emitted by irrigated rice fields could be lowered by 40%. In the case of intermittent floods, however, the $N_2O$ N fluxes may increase by 6%. The upscaling research for India has so revealed the challenge of GHG reduction. When intermittent floods repressed CO emissions, $N_2O$ emissions increased. Because $N_2O$ has a higher global warming potential (GWP), the benefits of lowering $CH_4$ and $CO_2$ fluxes are offset by increased $N_2O$. Total carbon equivalent emissions from irrigated rice-growing areas of the country fell from 41.1 Tg C to 36.2 Tg C in a year as a result of intermittent irrigation in lice. Rice direct seeding (DSR) and rice intensification (SRI) are two promising methods for reducing methane emissions. Methane is generated when the soil is constantly submerged in water, as in the case of conventional puddled transplanted rice. Methane emissions are reduced when rice is grown as an aerobic crop because DSR and SRI crops do not require continuous soil submersion. When compared to the traditional puddled transplanted rice farming method, DSR and SRI methods have a considerable potential to lower GWP (by around 35–75%).

## *9.18 Nutrient Management*

Site-specific nutrient management, slow-release nitrogenous fertilisers, and nitrification inhibitors such as coated calcium carbide and dicyandiamide are the most effective management options for lowering nitrous oxide emissions. Using a leaf colour chart (LCC) can reduce nitrous oxide and greenhouse gas emissions by 11–14%. Crops do not always absorb nitrogen efficiently from fertilisers, manures, biosolids, and other nitrogen sources. Improved N-use efficiency can reduce $N_2O$ emissions and indirectly reduce GHG emissions from fertiliser. That lead to $N_2O$ formation; placing N more precisely into the soil to make it more reachable to crop roots; or avoiding N application Climate change can be mitigated with the help of the INM and SSNM. Greater rice yields and hence increased net $CO_2$ assimilation, as well as a 30–40% increase in nitrogen utilisation efficiency, are instances of proven technology. This gives an excellent opportunity to reduce greenhouse gas emissions linked with nitrogen fertiliser use in rice systems. Better $CO_2$ concentrations may create thermal stress in many rice production systems in the future, but they will also allow for larger yields in settings when temperatures are not over threshold levels. As a result, prudent fertiliser use, a crucial component of the SSNM strategy, has a twofold benefit: it lowers GHG emissions while increasing yields in high $CO_2$ settings. In rice fields, the use of hydroquinone, a urea inhibitor, and dicyandiamide (DCD), a nitrification inhibitor, in combination with urea, is an effective way to reduce $N_2O$ and $CH_4$.

## *9.19 Soil Carbon Management Strategies*

It is crucial to manage soil organic carbon to maintain soil resilience to climate change. So soil carbon sequestration is a significant way to over come the climate change increased soil organic carbon (SOC) storage can help to slow climate change. Management techniques should be kept in place to ensure a positive net carbon transfer from the atmosphere to the soil. Soil sink capacity is reduced during the conversion of natural to agricultural ecosystems, as well as the drainage of wetlands, due to extensive tillage of soils and burning or removal of crop residue. Conversion to restorative land use and adoption management methods should be implemented to enrich the SOC pool. As a result, effective land use and management techniques must be maintained to promote both carbon storage in soil and other environmental services. This is an important strategy for climate moderation as well as improving rainfed system provisioning services.

Many long term experiment were started long back in India to enhance carbon sequestration and also for better productivity of different agro eco regions of the country. Appropriate land use and best management practices are found to increase carbon stock in rainfed situations. However, the exact sink capacity depends on prior SOM level and kind of land use system, climate, profile characteristics and the management practices implemented. Drylands have the obvious potential to play a significant role in climate mitigation while also providing significant co-benefits. Changes in dryland management practises can help increase carbon sequestration. Though dryland ecosystems have less carbon storage potential per unit area than moist tropical ecosystems, the prospect for carbon sequestration in dryland agriculture is enormous. On agricultural soils, the usual rate of SOC sequestration is 200–500 kg C/ha/year. Better management approaches increase carbon sequestration in soils. Crop residues as surface mulch, complex crop rotations and various farming systems, and integrated nutrient management (INM) strategies for recycling biosolids and other co-products are examples of these activities. Improving soil organic matter and biological nitrogen fixation through promoting soil fertility through integrated nutrient management.

SSNM (site-specific nutrient management) is a promising solution for climate change mitigation. Because it uses less inorganic fertilizer, SSNM increases agricultural productivity and helps mitigate climate change. The judicious application of inorganic fertiliser is a key component of the SSNM approach, as it has two benefits: it reduces greenhouse gas emissions while also improving yields under high $CO_2$ levels in the atmosphere. Cropping intensity is increased and both active and passive pools of SOC are maintained through crop rotation with winter cover crops.

## *9.20 Crop Residue Management and Carbon Sequestration*

Crop residues are the primary source of soil carbon, accounting for roughly 40% of total biomass on a dry weight basis. Crop residue is the biomass that remains in the field after grains and other valuable commodities have been harvested. Shoots, leaves, cobs, husk, and other above-ground components of agricultural wastes include shoots, leaves, cobs, and husk. Crop residues' ability to sequester carbon in soils could be a valuable asset in the fight against climate change and greenhouse gas emissions. The total input of crop residues that remain on the surface or are incorporated into the soil determines the concentration of organic C in the surface soil (0–15 cm). Farmers typically burn crop wastes such as pigeon pea and cotton stalks rather than reusing them. Therefore, shredding of crop residues is to be mechanised. Crop residues will decompose more easily and quickly in the soil or in vermicompost pits as a result of this.

Crop residue application to soil can be done in situ or ex situ in a variety of ways. Because agricultural leftovers and animal dung are correctly utilised directly into the soil with no nutrient loss, the in situ approach is the most efficient method of recycling organic residues. Crop residue application increases infiltration rate, improves soil characteristics, increases soil organic matter, encourages earthworm activity, and improves soil structure, resulting in a greater yield after four to seven years. Permanent crop cover with crop residue recycling is a prerequisite and key feature of conservation agriculture. Existing crop leftovers, however, cause agricultural swing problems. However, utilising machines such as the ziro till seed cum fertiliser drill or planters such as the happy seeder turbo seeder and rotary disc drill can assist to mitigate the issue. These devices are extremely effective at managing crop leftovers for moisture and nutrient conservation, as well as weed control and soil temperature regulation. Soil organic carbon is increased and carbon sequestration is aided by crop residue retention and nutrient application. Surface residues gradually decompose, improving soil organic matter status, biological activity, and diversity, and contributing to overall soil quality improvement. The C:N ratio in plant leftovers determines how quickly organic matter decomposes. C:N is the most commonly used criterion for determining the quality of residue. The legume's nitrogen source is critical for carbon sequestration regulation. Biomass carbon inputs as crop residue enhanced soil organic carbon and stock by a large amount each year.

## 9.21 Conservation Agriculture and Carbon Sequestration

The carbon sequestration in soil by adopting various agricultural practices broadly known as conservation agriculture and using this method may mitigate global climate change. There are mainly 3 basic principles up conservation agriculture. These three basic principles are minimum soil disturbance; coop residue cover end diversified crop rotation preferably with legumes. By combining information of carbon and nitrogen cycling in agriculture and summarising the impact of tillage, residue management, and crop rotation on soil organic carbon stock, the potential impact of conservation agriculture's own carbon sequestration can be better understood. Conventional tillage and erosion are the primary drivers of soil organic carbon loss. By lowering soil disturbance, shortening fallow times, and including cover crops into the rotation cycle, soil can store carbon when converted from plough till to no-till or conservation tillage. In dry and semi-arid environments, eliminating summer fallowing and replacing it with no-till with residue mulching improves soil structure, enhances filtration capacity, and lowers bulk density. However, the benefits of no-till on soil organic carbon sequestration may vary depending on the soil/site, and improvements in soil organic carbon may be inconsistent in fine-textured and poorly drained soil.

Growing cover crops in a rotation cycle greatly enhances the benefits of conservation tillage for soil organic carbon sequestration. Growing a leguminous cover crop improves biodiversity, residue quality, and the soil organic carbon pool. A high-biodiversity environment may absorb and sequester more carbon than a low-biodiversity ecosystem. The soil carbon sequestration is boosted by conservation agricultural system. Carbon sequestration in soil can be aided by increasing carbon inputs while reducing production. Soil organic carbon in conservation agriculture ranged between 0.31 and 0.45%, which is somewhat higher than in conventional agriculture (0.29–0.42%). Reduced tillage combined with crop residue retention raises soil organic carbon levels. Crop leftovers are a source of organic matter, and when degraded, they enhance the storage of soil organic carbon, hence removing them diminishes soil organic carbon greatly. Continuous application of manure and fertiliser in tropical Indian soils has shown that balanced fertilisation increased soil organic carbon and MBC. The higher amount of C mobilised in microbial biomass shows that soil organic matter supplies more labile C in conservation agricultural systems than in conventional systems. As a result, conservation agriculture likely provides a steady source of organic C to support the microbial community, as opposed to a conventional system, where each tillage event causes a temporary flush of microbial activity, resulting in large losses of C as $CO_2$. Although, due to high temperatures, tropical regions cannot trap carbon in soil. In some cropping systems, correct management approaches, particularly conservation agriculture, increase reasonable amounts of carbon sequestration, particularly in areas with heavy rainfall [47].

## *9.22 Bio-char and Carbon Sequestration*

When added to soil, biochar, a carbon-rich, fine-grained, porous byproduct of the pyrolysis process, improves soil fertility and increases soil carbon sequestration, among other environmental advantages [48]. The use of biochar in soil is seen as a novel way to create a significant, long-term, and considerable sink for atmospheric carbon dioxide in the terrestrial environment. It is thought to be a novel method of carbon sequestration in the terrestrial ecosystem. In India, annual biochar production is over 309 million tonnes, which may offset roughly half of carbon emissions (292 Tg C/year) by using biochar produced from fossil fuels [49].

Significant amounts of crop leftovers are produced in the Indo Gangetic plains of India from rice wheat cropping systems, and if these residues can be pyrolised, 50% of the carbon in biomass is returned to soil as biochar, increasing soil fertility and crop yields through carbon sequestration. When biochar is put to soil, it can permanently raise the carbon content of the soil and provide a carbon sink for $CO_2$ in the atmosphere. Essentially, it lowers atmospheric carbon dioxide by sequestering carbon that would otherwise be used to develop plants and other organic things in the earth. Biochar has the ability to trap huge amounts of carbon from the atmosphere. Bing conventional carbon capture and storage, new technologies are proposed for reducing carbon emission from coal fired power station, sequestration of biochar removes carbon from the atmosphere.

## *9.23 Agroforestry Systems in Carbon Sequestration*

To achieve the ecological and economic interaction of the various components in order to maximise productivity per unit area and time, woody perennials are introduced with crops, pastures, and livestock. The addition of trees to agricultural landscapes can boost system productivity by providing possibilities to produce carbon (C) sinks. Sequestration of carbon in agroforestry systems can be classified into two types: above-ground and below-ground plant components. The agroforestry system, which shape and environmental and socioeconomic conditions largely govern function, contributes significantly to carbon sequestration. In agroforestry, tree species and system management play a role in increasing carbon storage. The incorporation of carbon into plant matter is known as above-ground (vegetation) carbon sequestration.

The quantity of carbon sequestered in each section varies substantially based on a variety of parameters such as agro-climatic area, system type, site quality, historical land usage, and so on. The rates of above-ground carbon sequestration in some of the world's largest agroforestry systems range from 0.29 to 15.2 mg/ha/year. Agroforestry systems on fertile humid sites have a larger carbon sequestration potential than those on arid semi-arid and degraded sites, while tropical agroforestry systems have a higher sequestration potential than temperate agroforestry systems in general. Significant carbon is trapped in below-ground tree parts, with a portion of it added to the soil each year, contributing to soil carbon.

The tree-based systems also largely contribute significant amount of litter to the soil every year, which helps to increase the soil carbon. Different land use management with a higher potential to sequester carbon can enhance the carbon stocks in an ecosystem by removing atmosphere $CO_2$. The type of freshly stored carbon, changes in land use management, the ecosystem's inherent biological production, and the kind and thickness of soil all affect how quickly carbon is accumulated and released [50]. The carbon stored in soil in agroforestry systems ranges from 30 to 300 mg C/ha up to a depth of one metre, and the land conversion from worthless crops and grassland to agroforestry can result in a greater rate of carbon deposition that is to the tune of 3 tonnes/ha/year [51].

Carbon sequestration in agroforestry systems is determined by the quantity and quality of biomass contributed by trees and soil factors such as soil structure and aggregation. There is a 6.07 t/ha/year increase in soil carbon in a poplar system, and in sandy clay, higher carbon content was reported in the 0–30 cm depth compared to loamy sand. Carbon stock ranged from 8.5 to 15.2 mg C/ha in the upper 40 cm soil layer, which contained around 69% of soil carbon in the profile. Mixing agroforestry with crop fields is viable for increasing C sequestration in soils. Many types of agroforestry systems are common in India, and the following are the carbon sequestration rates recorded from these systems.

**Agri-silviculture systems**: Several sections of India have long practised agri-silvicultural systems. These systems can be classified into two groups. The first is farmers who plant trees in and around their fields where they grow food crops, and the second is farmers who plant trees in private holdings in diverse spatial arrangements where the main product is the tree, with the help of huge corporations. The tree can be cultivated in a variety of densities and spacing on boundaries or in the field.

**Silvo-pasture systems**: It is the practise of combining the growth of trees with the production of pastures and cattle. Many different silvo pastoral systems are practised in India. Scattered trees on pastures, plantation crops mixed with pastures, live fences, fodder banks, windbreaks and shelterbelts, and hedgerow intercropping on pastures are all examples of silvopastoral methods. Trees un silvopastoral systems provide protein-rich feed when grass is scarce or indigestible. In the Himalayan foothills and Rajasthan, there are several types of traditional silvopastoral systems, some of which are subsistence and migratory. These mechanisms help to sequester carbon.

### *9.24 Economic Impact of Climate Change and Climate-Smart Agriculture Technologies*

Despite the fact that climate change has few good benefits, global warming is a major harmful effect. Temperatures above 30 °C have net negative consequences, and temperatures exceeding 70 °C can result in severe loss. In 2015, the global social cost of carbon emissions is anticipated to be USD 29/tC (tonnes of carbon), rising at a rate of 2% per year [52]. If adequate climate change mitigation techniques can be implemented, the net economic growth of Solomon Island's fishery sector will also increase. Climate change will also have a negative impact on agricultural markets, resulting in a 0.26% drop in world GDP [53]. In a quadratic progression, both market and non-market losses have increased. If the average world temperature rises 1 °C, it is expected to cost 1.2% of GDP [54]. If future mitigation initiatives follow the adaption of previous strategies, global income is expected to drop by 23% by 2100, widening the income inequality gap [55]. Global economic growth is expected to slow by 0.28% annually [56].

## 10 Impact of National Programmes and Policies

### *10.1 Impact of Irrigation Policies*

Groundwater resources have been created in South Asian countries over the last 20 years. The average productivity of wheat, paddy, corn, and peanuts has increased to 2.97 Mt/ha from 2.32 Mt/ha. Irrigation policies have enhanced the resources for food as well as reduced the emission of greenhouse gases (GHGs) to a greater extent by avoiding the conversion of forest land to cropland. Among different types of irrigation processes, the Micro type irrigation smart technology has increased productivity to a greater extent which is almost triple time than the previous and saves water and energy too. In Indian agriculture for water utilization strategy "More crop per drop" is a very important message. Policies like MGNREGA and PMSKY (Prime Minister Krishi Sinchayee Yojana) significantly affected the country's conservation and utilization of groundwater. These irrigation programmes and policies has positive impact in both field crops and horticultural crops.

## *10.2 Impact of Fertilizer Policies*

South Asian countries have seen a fast increase in fertiliser consumption. The application of fertiliser has enhanced crop production and crop productivity in India. Due to the proper application of fertilizer, the production and productivity of the crop have been increased from the same piece of land, so the grain production has also been increased, saving a million hectares of forest land from conversion into cropland. The government's Soil Health Card objective has increased production and need-based nutrient application, as well as enhanced soil health. India plays a key role in climate change adaptation. The government has enacted legislation to minimise fertiliser input costs, enhance nutrient usage efficiency, and reduce GHG emissions from fertiliser nutrient sources. Neem-coated urea was introduced by India.

## *10.3 Agroforestry Policy*

The Government of India's forestry and agroforestry policies plays a critical role in climate adaptation and mitigation. The area under agroforestry is on an upward trend towards more carbon fixation and reduced GHGs. Aside from environmental services, including a price mechanism would help to stabilise the livelihoods of India's agroforestry producers. Through its network, ICAR supported location-specific agroforestry species identification and associated technology.

## *10.4 Livestock, Poultry and Fishery Sector Policies*

In order to combat animal diseases, develop genetic resources, implement scientific and improved management practises, increase production and abundance of healthy feed and fodder, develop processing and marketing facilities, and increase the productivity and profitability of livestock and fisheries enterprises, the Department of Agriculture and Allied Industries has been collaborating with state governments. In 2017–18, 176.3 million metric tonnes of milk were produced, up to 132.4 million metric tonnes in 2012–13. Several livestock-related measures contributed to India's overall development. In the financial year 2017–18, India's total fish production was anticipated to be around 12.61 million metric tonnes. Similar initiatives were taken to improve the poultry sector's administration and development.

## 10.5 Contingency Plans and Resilient Model Villages

ICAR's agriculture contingency plans and climate-resilient villages have the following main effects:

(a) A large-scale effective awareness was produced from multiple hierarchies and capacity building to roughly million stakeholders involved in resilient agriculture through various workshops, village institutions, interface meetings, field visits, and so on.
(b) Seed systems and agricultural machinery are available through Custom Hiring Centres for timely sowing and farm operations.
(c) In Madhya Pradesh, for example, essential technology were adopted for resilient agriculture, while crops in Andhra Pradesh were preserved using rain gun-based lifesaving irrigation.
(d) Drought years in the region (2014, 2015, 2016) resulted in a 6–9% reduction in sowing area. ICAR built a total of 151 resilient communities, which were then reproduced in state government programmes. Village carbon balances were improved by offsetting GHG emissions through the implementation of climate-resilient villages. The implementation of climate-resilient villages was a ground-up innovation involving multi-stakeholder participation, significant technical support, scientific knowledge flow, and regular monitoring.

## 10.6 Insurance Policies

Farmers' financial conditions have been improved by the implementation of insurance policies that lessen anguish and recompense for readiness. Under the Prime Minister Crop Insurance Scheme various chances have been provided to develop the farm insurance.

## 10.7 Agriculture and Rural Development Ministries Aggregated

In 2019 the Govt. of India bring two important ministers. They are the ministers of agriculture and rural development which are regulated or headed by a single minister and by combining these two ministries it is possible to implement climate change at ground level and it is expected to strengthen this thing further in India.

## 11 Conclusions

Providing food and nutrition security for the world's growing population has put a strain on agriculture, which is deteriorating further as a result of climate change. According to many studies, climate change is expected to reduce agricultural productivity in the coming years. Several mitigation and adaption strategies have been developed to mitigate the negative effects of climate change on agricultural sustainability. Climate change-related economic losses can be addressed using those methods at both the local and macro levels. However, in order to be effective, these mitigation and adaptation strategies must be planned at the regional or local level. Mitigation and adaptation planning is complicated by the fact that the future of climate change and its consequences is very unpredictable. This necessitates the development of climate-resilient technology based on a regional multidisciplinary approach. Farmers must be educated about various climate-smart technologies and climate-resilient cultivars must be produced. Climate change, its origins, and consequences are among science and technology's most rapidly changing topics. India is a tropical country whose agriculture sector is being impacted by climate change. Agriculture and sub-sectors employ over 70% of the Indian population directly or indirectly. Climate adaptation and mitigation measures can aid them in combating climate change's detrimental effects on agriculture.

## References

1. Asamoah EF, Beaumont LJ, Maina JM (2021) Climate and land-use changes reduce the benefits of terrestrial protected areas. Nat Clim Chang 11:1105–1110. https://doi.org/10.1038/s41558-021-01223-2
2. FAO (2011) Climate change, water and food security, FAO water reports
3. Seneviratne SI, Nicholls N, Easterling D, Goodess CM et al (2012) Changes in climate extremes and their impacts on the natural physical environment. In: Field CB, Barros V, Stocker TF, Qin D, Dokken DJ, Ebi KL, Mastrandrea MD, Mach KJ, Plattner G-K, Allen SK, Tignor M, Midgley PM (eds) 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 (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp 109–230
4. Raza A, Razzaq A, Mehmood S, Zou X, Zhang X, Lv Y, Xu J (2019) Impact of climate change on crops adaptation and strategies to tackle its outcome: a review. Plants 8(2):34. https://doi.org/10.3390/plants8020034
5. Levidow L, Zaccaria D, Maia R, Vivas E, Todorovic M, Scardigno A (2014) Improving water-efficient irrigation: prospects and difficulties of innovative practices. Agric Water Manag 146:84–94. https://doi.org/10.1016/j.agwat.2014.07.012
6. McMichael AJ et al (2000) The sustainability transition: a new challenge (editorial). Bull World Health Organ 78:1067
7. FAO (2014) Agriculture, forestry and other land use emissions by sources and removals by sinks climate, energy and tenure division, FAO
8. Goudrian J, Unsworth MH (1990) Implications of increasing carbon dioxide and climate change for agricultural productivity and water resources. In: Impact of carbon dioxide, trace cases and

climate change on global agriculture. american society of agronomy (ASA) special publication no. 53. ASA, Madison, WI, USA, pp 111–130
9. Pant GB, Rupa Kumar K, Parthasarathy B (1993) Observed variation in rainfall and surface temperature over India. In: Global warming: concern for tomorrow (Lal M (ed)). Tata McGraw-Hill, pp 71–91
10. Hingane LS, Rupa Kumar K, Ramana Murty BV (1985) Long-term trends of surface air temperatures in India. J Climatol 5:521–528
11. OECD (2017) Working with change: systems approaches to public sector challenges
12. Bal SK, Minhas PS (2017) Atmospheric stressors: challengesand coping strategies, In: Minhas PS et al (eds) Abiotic stress management for resilient agriculture. Springers Nature Singapore Pte. Ltd., pp 9–50. https://doi.org/10.1007/978-981-10-5744-1_2 (2) (PDF) Challenges and Opportunities in Weather Based Crop Insurance in India. Available from: https://www.researchgate.net/publication/333389271_Challenges_and_Opportunities_in_Weather_Based_Crop_Insurance_in_India#fullTextFileContent [accessed Aug 25 2023]
13. Slinivasarao C, Deshpande AA, Venkateswarlu B, I-al R, Singh AK, Kundu S, Vittal KPR, Mishra PK, Prasad JVNS, Mandal UK, Sharma KL (2012) Grain yield and carbon sequestnuion potential of post monscx•n sorghum culuvation in Vertisols in the semi-arid tropics of central India. Geodenna 175–176:90–97
14. Ahluwalia VK, Malhotra S (2006) Environmental science. Anne Books India, New Delhi
15. Ton (2011) International trade centre (ITC). Cotton and climate change: impacts and options to mitigate and adapt. ITC, Geneva
16. Aggarwal PK (2009) Global climate change and indian agriculture: case studies from the Indian council of agricultural research network pmiect. ICAR, New Delhi, p 148
17. Saseendran ASK, Singh KK, Rathore LS, Singh SV, Sinha SK (2000) Effects of climate change on rice production in the tropical hunud climate of Kerala, India. Clim Chang 44:495–514
18. Bahl PN (2015) Climate change and pulses: approaches to combat its impact. Agric Res 4(2):103–108
19. Kirschbaum MUF (2004) Direct and indirect climate change effects on photosynthesis and transpiration. Plant Biol 6:242–253
20. Mall R, Singh R, Gupta A, Srinivasan G, Rathore L (2006) Impact of climate change on Indian agriculture: a review. Clim Change 74:225–231
21. Stanhil G, Cohen S (2001) Global dimming: a review of the evidence for a wide spread and significant reduction in global radiation with discussion of its probable causes and possible agricultural consequences. Agric For Meteorol 107:255–278
22. Dagar JC, Singh AK, Singh R, Arunachalum A (2012) Climate change vis-a-vis Indian agriculture. Ann Agric Res New Ser 33(4):189–203
23. Bowes G (1993) Facing the inevitable: plants and increasing atmospheric $CO_2$. Annu Rev Plant Physiol Plant Mol Biol 44:309–332
24. Sage RF, Kubien DS (2007) The temperature response of $C_3$ and $C_4$ photosynthesis. Plant Cell Environtnent 30:1086–1106
25. Lara MV, Andreo CS (2011) $C_4$ plants adaptation to high levels of $CO_2$ and to drought environments, Abiotic stress in plants-mechanisms and adaptations (ArunShanker (ed)). ISBN: 978-953-307394-1. InTech, http://www.intechopen.com/books/abiotic-stress-in-plantsmechanismsandadaptations/c4plantsadaptationtohighlevelsofCO2andtodroughtenvironments
26. Patterson IT (1995) Weeds in a changing climate. Sciences 43:685–701
27. World Bank (2008) World Bank's approach to climate change in South Asia: an overview. Bank Information Center. www.bicusa.org
28. Srinivasa Rao C, Prasad RS, Mohapatra T (2019) Climate change and Indian agriculture: impacts, coping strategies, programmes and policy. Technical bulletin/policy document 2019. Indian Council of Agricultural Research, Ministry of Agriculture and Farmers' Welfare and Ministry of Environment, Forestry and Climate Change, Government of India, New Delhi, p 25
29. Kumar R, Kumar KK (2007) Managing physiological disorders in litchi. Indian Hortic 52(1):22–24

30. Pereira AMF, Baccari F Jr, Titto EAL, Almeida JAA (2008) Effect of thermal stress on physiological parameters, feed intake and plasma thyroid hormones concentration in Alentejana, Mertolenga, Frisian and Limousine cattle breeds. Int J Biochem 52:199–208
31. Chowdhury QM, Monzur K (2016) Impact of climate change on livestock in bangladesh: a review of what we know and what we need to know. Am J Agric Sci Eng Technol 3(2):18–25–via e-palli. http://ajaset.e-palli.com/wpcontent/uploads/2013/12/impactof-climate-change-on-livestock-inbangladesh-a-review-of-what-weknow-and-what-we-need-toknow.pdf
32. Singh SK, Meena HR, Kolekar DV, Singh YP (2012) Climate change impacts on livestock and adaptation strategies to sustain livestock production. J Vet Adv 2(7):407412
33. Dash S, Chakravarty AK, Singh A, Upadhyay A, Singh M, Yousuf S (2016) Effect of heat stress on reproductive performances of dairy cattle and buffaloes: a review. Vet World 9(3):235–244
34. West JW (2003) Effect of heat stress on production in dairy cattle. J Dairy Sci 86:21312144
35. Musemwa L, Muchenje V, Mushunje A, Zhou L (2012) The impact of climate change on livestock production amongst the resource-poor farmers of third world countries: a review. Asian J Agric Rural Dev 2(4):621–631
36. Geraert PA, Padilha JC, Guillaumin S (1996) Metabolic and endocrine changes induced by chronic heat exposure in broiler chickens: growth performance, body composition and energy retention. Br J Nutr 75:195–204
37. Deng W, Dong XF, Tong JM, Zhang Q (2012) The probiotic Bacillus licheniformis ameliorates heat stress-induced impairment of egg production, gut morphology, and intestinal mucosal immunity in laying hens. Poult Sci 91:575–582
38. Lin H, Mertens K, Kemps B, Govaerts T, De Ketelaere B, De Baerdemaeker J, Decuypere E, Buyse J (2004) New approach of testing the effect of heat stress on eggshell quality: mechanical and material properties of eggshell and membrane. Br Poult Sci 45:476–482
39. Miller PC, Sunde ML (1975) The effects of precise constant and cyclic environmental on shell quality and other performance factors with Leghorn pullets. Poult Sci 54:36–46
40. Morgan I, McDonald DG, Wood CM (2001) The cost of living for freshwater fish in a warmer, more polluted world. Glob Change Biol 7:345–355
41. Vivekanandan E, Ratheesan K, Manjusha U, Remya R, Ambrose TV (2009) Temporal changes in the climatic and oceanographic variables off Kerala. In: Vivekanandan E et al (eds) Marine ecosystems challenges and opportunities. Book of Abstracts, Marine Biological Association of India, Cochin, pp 260–261
42. IPCC (2001) Impacts, adaptations and vulnerability of climate change: contribution of working group Il to the third intergovernmental panel on climate change (Mc Canhy JJ, Canjiani OF, Leary NA, Dokken DJ, White KS (eds)). Cambridge University Press. Cambridge, UK
43. IPCC (2001) Climate change: the scientific basis, p 881. Contribution of working group I to the third assessment report of the international panel on climate change (Houghton JT, Ding Y, Griggs DJ, Noguer M, van der Linden PJ, Dai X, Mskell K, Johnson CA (eds)). Cambridge University Press, Cambridge, UK
44. Ravindra Chary G, Venkateswarlu B, Sharma SK, Mishra JS, Rana DS, Ganesh Kute. (2012). Agronomic research in dryland f•Mning in India: an oseniew. Indian J Agron 57 (3rd IAC special issue):157–167
45. AICRPDA (2003) Annual reports 1971–2001. Eldo scope electronic document. All India co-ordinated research project for dryland agriculture (AICRPDA), central research institute for dryland agriculture (CRIDA), Hyderabad, India, p 6357
46. Venkateswarlu B, Singh AK, Prasad YG, Ravindra Chary G, Srinivasa R, Rao KV, Ramana DBV, Rao VUM (2011) District level contingency plans for weather aberrations in India. Central Research Institute for Dryland Agriculture, Indian Council of Agricultural Research, Hyderabad, Andhra Pradesh India, p 136
47. Srinivasarao C, Vankateswarlu B, Lal R, Singh AK, Kundu Vittal KRR, Balaguruvaiah G, Vijaya Shankar Babu M, Ravindra Chary G, Prasadbabu MBB, Yellamanda Reddy T (2012) Soil carbon sequestration and agronomic productivity of an alfisol for a groundnut-based system in a semiarid environment in southern India. Eumpean J Agron 43:40–48
48. Lehmann J (2007) A handful of carbon. Nature 447:143–144

49. Lal R (2005) World cop residues production and implication of its use as a biofuel. Environ Int 31:575–586
50. Watson D (2000) Mood and Temperament. New York: Guilford Press
51. Nair PKR, Nair VD, Kumar BM, Showalter J (2010) Carbon sequestration in agroforestry systems. Adv Agron 108:237–307. https://doi.org/10.1016/S0065-2113(10)08005-3
52. Tol RSJ (2012) On the uncertainty about the total economic impact of climate change. Environ Res Econ 53:97–116
53. Costinot A, Donaldson D, Smith C (2016) Evolving comparative advantage and the impact of climate change in agricultural markets: evidence from 1.7 million fields around the world. J Pol Econ 124:20–25
54. Hsiang S, Kopp R, Jina A, Rising J, Delgado M, Mohan S, Rasmussen DJ, Muir-Wood R, Wilson P, Oppenheimer M et al (2017) Estimating economic damage from climate change in the United States. Science 356:1362–1369
55. Burke M, Hsiang SM, Miguel E (2015) Global non-linear effect of temperature on economic production. Nature 527:235–239
56. Carleton TA, Hsiang SM (2016) Social and economic impacts of climate. Science 353:9837
57. Ciscar JC, Iglesias A, Feyen L, Szabo L, Regemorter DV, Amelung B, Nicholls R, Watkiss P, Christensen OB, Dankers R et al (2011) Physical and economic consequences of climate change in Europe. Proc Natl Acad Sci USA 108:2678–2683
58. IPCC (2006) IPCC guidelines for national gas inventories. http://www.ipcc.nggip.iges.or.jp
59. Li CS, Frolking S, Frolking TA (1992) A model of nitrous-oxide evolution from soil driven by rainfall events. 2. Model applications. J Geophys Res-Atmos 97(9):9777–83
60. Olivier JG, Schure KM, Peters JAHW (2017) Trends in global $CO_2$ and total greenhouse gas emissions. PBL Neth Environ Assess Agency 5
61. Srinivasarao C, Venkateswarlu B, Lal R, Singh AK, Kundu S, Vittal KPR, Sharma SK, Sharma RA, Jain MP, Rasåndra Chary G (2012) Sustaining agronomic prcxiuctivity and quality of a Vertisolic soil (Vertisol) under soybean-safflower croppmg system in semi-arid central India. Can J Soil Sci 92(5):771–785