International Journal of Engineering, Science and Humanities
An international peer reviewed, refereed, open access journal
Impact Factor: 8.3 www.ijesh.com ISSN: 2250 3552

Impact of Climate Change on Plant Growth and Biodiversity

Sahil Dehraj
M.Sc Botany (Deptt. of Botany, MDU), CSIR-NET (Qualified)
sahilnub13@gmail.com

Abstract
Climate change is one of the most serious environmental challenges affecting plant growth, Biodiversity and agriculture systems. It is the change that is experienced in terms of temperature, rainfall, humidity, wind patterns, seasonal cycles and extreme weather events over a long period of time. Global warming is caused due to human activities like deforestation, industrialization, urbanisation, burning of fossil fuels and overexploitation of natural resources which have led to increase in greenhouse gases like carbon dioxide, methane, nitrous oxide etc. These climatic changes are very sensitive to plants because in the growth of plants, it requires temperature, sunlight, water, soil nutrients and atmospheric gases. Climate change leads to impacts on seed germination, root growth, photosynthesis, respiration, flowering, fruiting and the production of seeds. Drought stress due to rising temperature and irregular rainfall leads to low soil moisture and low plant productivity. It also has impacts on biodiversity, such as altering the distribution of species, habitat loss, introduction of invasive species and endangering rare and endemic plants. Agricultural ecosystems, mountains, wetlands and forests are particularly sensitive. The loss of traditional seed varieties, wild relatives of crops, soil microorganisms and pollinators are also contributing to the loss of agricultural biodiversity. Thus, conservation of plant biodiversity, afforestation, establishment of seed banks, gene banks, sustainable agriculture and climate resilient crop varieties are crucial to mitigate the adverse effects of climate change and ensure ecological balance.

Keywords: Climate change, global warming, plant growth, biodiversity, greenhouse gases, photosynthesis, seed germination, drought stress, habitat loss

Introduction

Climate change is one of the greatest environmental issues of today. It is a change in temperature, rainfall, humidity, wind pattern, seasonal cycles and extreme weather conditions over a long period of time. Climate change is a natural phenomenon but today has been accelerated, primarily due to environmental-human activities like deforestation, industrialization, urbanization, burning of fossil fuels, and the overuse of natural resources. These activities contribute to creating more carbon dioxide, methane and nitrous oxide in the atmosphere. As a result of this, global temperature has been increasing and nature's equilibrium is being disrupted. Climate conditions are very important for plants as the growth and development of the plant is directly linked to the temperature, light, water, soil nutrients, and atmospheric gases. All of these environmental factors have an impact if they change, on the normal life cycle of plants. The effects of climate change are on seed germination, root growth, stem development, leaf growth, flowering, fruiting, and seed

International Journal of Engineering, Science and Humanities
An international peer reviewed, refereed, open access journal
Impact Factor: 8.3 www.ijesh.com ISSN: 2250 3552

production. In many parts, the soil's water has been depleted due to an increase in temperature and irregular rainfall; causing drought stress in plants. It makes the plants grow slowly, less productive and with less survival. However, changes in photosynthesis and respiration also affect plant growth. In photosynthesis, plants use sunlight, water and carbon dioxide to make their food. The rate of photosynthesis can also change if temperature and carbon dioxide levels are changed. When water and nutrients are limited, it is not always advantageous to increase carbon dioxide, as such, but rather it may be beneficial to increase carbon dioxide where it is already present and abundant. As the temperature rises respiration and water loss by transpiration are increased and the plant body is weakened. Thus, climate change leads to a disturbance of plant's physiological events.

Biodiversity is also greatly affected by climate change. Biodiversity is defined as the diversity of organisms that inhabit a specific region, including plants, animals and microorganisms. The importance of plant biodiversity is that it helps maintain an ecological balance, food chain, soil protection, oxygen, food, medicine, timber, fibre etc. Many species do not cope with the changes in climate. This can result in decline of the population, species migration, loss of habitat and even the extinction of rare and endemic plants. The distribution of plant species is also changing due to climate change. Some plants are moving towards cooler climates, into higher elevations, or into better habitats. Not all species can, however, move or adapt rapidly. Limited-distributed, slow-reproducing, and/or habitat-specific species are more vulnerable. The forest ecosystems, grasslands, wetlands, coastal vegetation as well as mountain flora are particularly sensitive to the effects of climate change. Altered climate conditions may also contribute to the rapid spread of invasive plants, which can also disrupt native biodiversity.

Climate change also has an impact on agricultural plants. The crops require frequent rainfall, proper temperature and soil fertility for their proper growth. Food security is threatened by irregular monsoon, heat waves, flood and drought, which affects crop yield. Environmental changes could also cause the loss of traditional varieties and crop wild relatives. Lack of agricultural biodiversity can limit the ability of a farming system to cope with future climate change. Therefore, the effect of climate change on plants growth and biodiversity is of great significance in the study of Botany and Environmental Science. It enables us to learn about plant responses to a changing climate and how biodiversity can be safeguarded. Conservation of plant biodiversity, sustainable agriculture, afforestation, seed banks and gene banks and climate-resilient crop varieties are some key measures to mitigate the adverse impact of climate change. For this reason, it is pertinent to understand the relationship between climate change, plant life and ecological stability, and this is the focus of this topic.

Climate change is a change in the average weather over the long-term, particularly in the mean temperature, precipitation, humidity, winds and seasons of the Earth. It is not only a short-term change in weather, but a continuous change that takes place over a long period of time. Climate change may occur due to natural causes such as volcanic eruptions, solar radiation and natural

International Journal of Engineering, Science and Humanities
An international peer reviewed, refereed, open access journal
Impact Factor: 8.3 www.ijesh.com ISSN: 2250 3552

changes in the Earth's atmosphere. But today, climate change is primarily due to human actions like deforestation, industrialization, using coal, petrol and diesel, urbanisation and excessive utilisation of natural resources. The leading cause of modern climate change is the rise in Green House Gases in the atmosphere. Carbon dioxide, methane and nitrous oxide are some of the gases that are able to retain heat from the sun and warm the earth. This is called "global warming. In response to the natural climate system, global warming leads to increases in temperature, melting glaciers, rising sea level, irregular rainfall, droughts, floods, heat waves and shifts in the seasonal cycle. Climate Change affects all living things, including plants and animals, human beings and ecosystems. Climate extremes affect plants, particularly as their growth is influenced by temperature, water, sunlight and soil moisture. Plant growth, flowering, fruiting, production of seeds and biodiversity are also impacted by changes in climate. Thus, climate change is a significant environmental problem with impact on nature equilibrium and huge problems for plant life and agriculture conservation.

Image 1: *Impact of Climate Change on Crop Growth*

This image shows the serious impact of climate change on crop growth. The dry and cracked soil refers to drought due to increasing temperature and variability in rain fall. Withered and damaged crops indicate a lack of water and nutrients for good crop development. Seed germination, root growth, photosynthesis and crop productivity are severely impacted by excessive heat and moisture deficiency in the soil. This causes the loss in yield and issues for farmers and food security. The image is clearly a depiction of the impact of climate change on agriculture and the vulnerability of crops to drought and heat stress.

Climate Change: An Overview

Climate change is defined as long-term changes in the Earth's climate such as changes in temperature, precipitation, humidity, wind and weather, and seasonal cycles and the frequency of extreme weather events. Weather differs from climate because weather can vary from day to day

International Journal of Engineering, Science and Humanities
An international peer reviewed, refereed, open access journal
Impact Factor: 8.3 www.ijesh.com ISSN: 2250 3552

and weather can change over a century or more, depending on the climate change. The interaction between the atmosphere, oceans, land surface, ice sheets, forests and living organisms govern the Earth's climate system. When this balance is upset, the climate starts to shift in an unusual manner. With the present times, the climate change has emerged as a gigantic environmental issue all over the world due to the rise in the concentration of heat-trapping gases in the atmosphere, caused by human activities. Fossil fuel combustion, petrol, diesel and natural gas, deforestation, industry, urban development and intensive agriculture are sources of high levels of GHGs. These gases increase the temperature of the Earth and disturb the natural climate system. Consequently, global temperature is increasing, glaciers are melting, rainfall is becoming more irregular, droughts and floods are becoming more common, as are heat waves, cyclones and shifts in the length of the seasons. Climate change has direct impacts on growth of plants and biodiversity. Stable environment conditions are essential for plant germination, photosynthesis, flowering, fruiting and reproduction. As plants get hotter or drier, they become stressed. Many sensitive, rare and endemic plant species may suffer decline or disappear, some may adapt. Thus, climate change is not just an atmospheric problem, but one of profound ecological concern relating to forests, grasslands and wetlands, as well as agriculture and biodiversity overall.

Greenhouse Effect and Global Warming

The greenhouse effect is a natural phenomenon which keeps the Earth warm enough for life. Solar radiation from the Sun is in the form of short wave radiation reaching the Earth. Part of this energy is reflected back into space and the rest is absorbed by the earth's surface. The earth takes up the energy from the sun and then radiates heat in the form of long wave infrared radiation. Some of this heat is absorbed by the so-called ‘greenhouse gases' in the atmosphere, and doesn't all go back out again to space. This heat is retained in the earth and sustains the possibility of life. If the Earth did not have the natural greenhouse effect, it would be very cold and uninhabitable. But the challenge starts with the excess amount of greenhouse gases over the natural concentration. Carbon dioxide, methane, nitrous oxide and other greenhouse gases have been abundantly released into the atmosphere due to human activities. These gasses retain more heat than usual, which raises the average temperature of the Earth. This is an increased greenhouse effect and this is the primary cause of global warming. Global warming is an increase in the average temperature of the Earth's atmosphere and surface. It is mainly caused by the increased concentration of greenhouse gases due to human activities. Global warming leads to several environmental changes such as melting of glaciers, rise in sea level, increase in heat waves, changes in rainfall patterns and disturbance in ecosystems. Global warming may impact plant growth rate, photosynthesis, flowering, seed production and survival. Increased CO_2 levels might induce growth in some plants, but this effect might be reduced if there is an interaction between high temperature, water deficit, and nutrient deficiency. The greenhouse effect is a natural and essential process, but the enhanced greenhouse

International Journal of Engineering, Science and Humanities
An international peer reviewed, refereed, open access journal
Impact Factor: 8.3 www.ijesh.com ISSN: 2250 3552

effect because of human activities leads to global warming. Global warming also helps to drive climate change and poses significant problems for plants, farming, forests and biodiversity.

- **Major Greenhouse Gases**

Greenhouse Gases are gases that are found in the atmosphere that capture and retain heat. These gases permit the transmission of sunlight to the earth's surface, and they limit the release of heat back into space. The principal GHGs are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), water vapour, ozone and fluorinated gases. Each gas originates from a different source, has a different lifetime in the atmosphere, and has a different radiative forcing. Carbon dioxide is a key greenhouse gas in the contemporary climate change. It is primarily emitted from burning fossil fuels like coal, petroleum and natural gas. Other sources of CO2 emissions include industrial activities, transportation, electricity production, and deforestation. Forests are a carbon sink because they absorb carbon dioxide into the plant during photosynthesis. With the removal and/or combustion of forests, the amount of carbon dioxide in the atmosphere rises. Increased CO2 levels can increase growth of some plants in the early stages, but as temperatures and water stressors increase this benefit will diminish.

Another greenhouse gas is methane. It is free of agricultural activities, rice fields, livestock, wetlands, landfills and coal, oil and natural gas production. While methane will stay in the atmosphere for less time than carbon dioxide, it has a much greater heat-trapping capability. The emission of methane is closely associated with agricultural activities such as paddy cultivation and animal husbandry. So higher levels of methane can lead to global warming, which can have an indirect impact on plant habitats and biodiversity. The primary sources of nitrous oxide are agricultural soils, chemical fertilisers, animal wastes, biomass burning and some industrial sources. It is a potent greenhouse gas and is also a depleter of ozone. Nitrogen-based fertilizers will contribute to more nitrous oxide emissions if over used. This connects climate change and contemporary farming practices together. N2O plays a role in warming, impacts soil moisture, crop growth and natural vegetation. Water vapour is the most abundant GHG in the atmosphere. It is released as a natural process when it evaporates from oceans, rivers, lakes and soil, as well as by transpiration from plants. Important role of water vapour in the natural greenhouse effect. As global temperature rises, however, so too does the evaporation rate, and thus the amount of water vapour in the atmosphere. This continues the enhancements to warming. Water vapour also plays a vital role in the formation and precipitation of clouds, relative humidity and precipitation, which are significant for development and balance of the ecosystem and plant growth.

Ozone also acts as a greenhouse gas, however, with location specific effects to its impact. Stratospheric O3, or ozone in the upper atmosphere, blankets the earth with ozone and prevents the harmful UV rays from reaching the surface. But ground level ozone is a bad thing. It is formed due to pollution from vehicles, industries and chemical reactions in sunlight. It degrades the leaves of plants, it affects the ability of plants to photosynthesize and it interferes with plant productivity

International Journal of Engineering, Science and Humanities
An international peer reviewed, refereed, open access journal
Impact Factor: 8.3 www.ijesh.com ISSN: 2250 3552

at ground-level ozone. The fluorinated gases are man-made gases emitted from industrial processes, refrigeration, air conditioning and the electronics industry. There are other gases, which are found in smaller amounts, but have high trapping ability. They hang in the air for a long time and are important greenhouse gases. Their impact on plants is limited but their contribution to climate change is indirect and thus impacts on ecosystems and biodiversity. Hence, the GHGs are very relevant in climate change. Their overproduction upsets the heat balance of the earth, leads to global warming and impacts natural systems. Greenhouse Gases are significant in the context of plant growth and biodiversity because they affect soil moisture, habitat stability (and species survival), temperature and rainfall.

Impact of Climate Change on Plant Growth

However, plants are closely linked to environmental conditions and climate change has a direct and serious impact on plant growth. Plants grow and develop under the influence of temperature, rainfall, humidity, sunlight and soil moisture and atmospheric gases. As the climatic factors change, the normal physiological and biological activities of the plants are affected. Seed germination, root growth, leaf growth and development, photosynthesis, respiration, flowering, fruiting and seed production are all impacted by climate change. Many plants are under stress as a result of the increase in temperature, irregular rainfall, drought or floods and the increased concentration of carbon dioxide. These stress conditions impact plant productivity, plant health and ecosystem balance. Growth is dependent on the appropriate climate and environment. Each plant species has an optimum growth temperature and moisture level. Plants grow normally when the climate conditions are within this suitable range. However, if there is a rise in temperature above tolerance or scarcity of water, then the plants will not be able to carry out their life functions. Therefore, the height of the plant, leaf area, biomass production, root growth and reproductive capacity may be reduced. Hence, the climate change is one of the important factors affecting the nature vegetation and agricultural crops.

Image 2: *Pollinators and Plant Biodiversity*

International Journal of Engineering, Science and Humanities
An international peer reviewed, refereed, open access journal
Impact Factor: 8.3 www.ijesh.com ISSN: 2250 3552

This image shows the important relationship between pollinators and plant biodiversity. The bee moving towards the flower represents the process of pollination, in which insects transfer pollen from one flower to another and help plants produce fruits and seeds. Pollinators such as bees, butterflies and other insects play a very important role in maintaining plant diversity and agricultural productivity. Due to climate change, rising temperature and changes in flowering time can disturb this natural relationship. Sometimes flowers bloom earlier or later, while pollinators may not be available at the same time. This mismatch reduces pollination, affects seed formation and threatens plant reproduction. Therefore, the image clearly shows that protecting pollinators is essential for conserving plant biodiversity and maintaining ecological balance.

Effect of Temperature Rise on Plant Growth

Climatic factors that influence plant growth include temperature. All plants have a temperature range at which they can grow well. Growth rate of some plants can be accelerated by moderate temperature rise in cooler areas. However, too much heat causes heat stress which is a negative impact on plant growth and development. The high temperature disrupts cell division and enzyme activity, water absorption and nutrient uptake and overall metabolism of plants. Evaporation and transpiration increase with an increase in temperature. Transpiration is the loss of water from the leaves of plants. When water loss is too high, it leads to water stress in plants, particularly at low moisture availability. Water stress can cause leaves to be dry, curled or yellow. Turgidity of plant cells is lost, leading to decreased growth and plant structure. In extreme instances, plants can cease to grow or perish.

The impact of high temperature is also on root and shoot development. The roots may not develop in-depth or robust structures when subjected to heat stress, limiting water and mineral uptake from the soil. Shoot growth can also be slow due to the allocation of more energy to survival than growth. Leaf size may be reduced and leaf area may be lost. The reduction in leaf area reduces the food production of plants, especially leaves are the primary organ in which photosynthesis occurs. The reproductive stage of plants is also influenced by the rise in temperature. The flowering, pollination, fruit set and seed development all have a strong temperature sensitivity. Temperatures can be too high and cause flower drop, disturb fertilization and reduce pollen viability. In crop plants, this leads to poor quality seeds or fruits and yield losses.

For instance, heat stress can have a significant effect on grain development in cereals and fruit set in fruit crops. An increase in temperature will alter plant species distribution in natural ecosystems. Some plants may shift towards cooler regions or higher altitudes. Many plants, however, cannot move rapidly enough, particularly those that have slow rates of reproduction and/or low seed dispersal. A species could suffer a decline in numbers or die out. Therefore, the temperature rise not only influences the growth of individual plants, but also plant communities and biodiversity.

International Journal of Engineering, Science and Humanities
An international peer reviewed, refereed, open access journal
Impact Factor: 8.3 www.ijesh.com ISSN: 2250 3552

Table 1: *Effects of Temperature Rise on Plant Growth*

S. No.	Aspect of Plant Growth	Effect of Temperature Rise	Result on Plant Growth
1	Seed Germination	High temperature reduces or delays seed germination	Poor seedling growth
2	Photosynthesis	Excess heat lowers photosynthetic activity	Less food production in plants
3	Respiration	Temperature rise increases respiration rate	More energy loss and reduced growth
4	Water Balance	High temperature increases transpiration	Wilting and dehydration
5	Flowering and Pollination	Heat stress affects flowering time and pollen viability	Poor fruit and seed formation
6	Crop Productivity	Continuous heat stress reduces overall plant growth	Low yield and poor quality produce

The table explains how rising temperature affects different stages and processes of plant growth. High temperature directly influences **seed germination** by delaying or reducing the germination process, which results in poor seedling growth. It also affects **photosynthesis**, because excess heat reduces the ability of plants to prepare food through sunlight, water and carbon dioxide. As a result, food production in plants decreases and their growth becomes weak. Temperature rise also increases the rate of **respiration**, due to which plants use more energy for survival and less energy remains available for growth and development. The table also shows that high temperature disturbs the **water balance** of plants. Due to excessive heat, transpiration increases and plants lose more water through their leaves. This causes wilting, dehydration and weakness in plant tissues. **Flowering and pollination** are also highly sensitive to heat stress. High temperature can change flowering time and reduce pollen viability, which leads to poor fruit and seed formation. Finally, continuous heat stress reduces overall **crop productivity**. It affects plant height, biomass, fruit quality and yield. Therefore, the table clearly shows that temperature rise creates serious stress for plants and negatively affects their growth, reproduction and agricultural productivity.

Changes in Photosynthesis and Respiration

Plants have two important physiological processes – photosynthesis and respiration. Green plants use carbon dioxide, water and the Sun to produce their food, this is called photosynthesis. It is

International Journal of Engineering, Science and Humanities
An international peer reviewed, refereed, open access journal
Impact Factor: 8.3 www.ijesh.com ISSN: 2250 3552

predominantly carried out in leaves with the help of chlorophyll. Plants use photosynthesis to create glucose and to release oxygen. This process helps in the growth of plants, increase in biomass production, and the food chain as a whole. Photosynthesis is impacted by climate change in a few ways. The heightened atmospheric carbon dioxide will boost the photosynthetic growth rate of some plants, particularly C3 plants like wheat, rice, and soya bean. This is sometimes referred to as the carbon dioxide fertilization effect. But, this positive effect is not always permanent or adequate. Plants cannot fully take advantage of higher carbon dioxide levels in the atmosphere if they do not have sufficient water, nutrients and temperature. Thus, in some situations, climate change can enhance photosynthesis while in stressful situations, it can decrease photosynthesis. Plants can be harmed by high temperatures because they can adversely affect the photosynthetic machinery. Photosynthesis enzymes are most active in a certain temperature range. If the temperature is too high, enzyme activity is affected and the chlorophyll may be damaged. This starves the plant of sunlight and energy which it can use to make food. Stomata also close due to heat stress. The leaves have small pores called stomata through which carbon dioxide is taken up and water vapour is lost. If stomata open, water escapes, but carbon dioxide is taken in and photosynthesis occurs at a faster rate.If stomata close to conserve water, carbon dioxide will not be taken up and photosynthesis will decrease.

Climate change-induced drought also affects photosynthesis. Without enough water plants cannot carry on normal metabolic activities. Water deficiency causes a decrease in chlorophyll, leaf area and stomatal size. As a result, the rate of photosynthesis decreases. Leaf fall, decreased growth and poor productivity can result from prolonged drought. The other important process in plants is respiration. Plants use respiration to get energy from food in order to grow and develop. Respiration takes place during the day and night while photosynthesis does not. As temperatures rise, respiration rates will go up. If the respiration rate is too high, plants use up more food and energy. This decreases food reserves for growth, flowering and seed setting. Photosynthesis and respiration in plants is critical for plant growth. Photosynthesis creates food and respiration utilizes food for energy. If respiration and photosynthesis rates are equal, the plant will not grow in normal conditions. However, with climate stress, photosynthesis could drop while respiration rises. This imbalance will decrease biomass production and weaken the growth of plants. So, the impact of climate change on plant productivity is on the balance between photosynthesis and respiration.

Impact on Seed Germination

Seed germination is the first and crucial step in a plant's lifetime. The development of a seedling seed from a favourable condition. Seeds need the right temperature, moisture and oxygen for germination and in some cases light. All these factors are influenced by climate change and so are also significantly influencing germination. Temperature is an important factor in seed germination. All plant species will have an optimum temperature range for germination. Too cold or too hot may cause slow germination or no germination at all. A warmer climate as a result of climate

International Journal of Engineering, Science and Humanities
An international peer reviewed, refereed, open access journal
Impact Factor: 8.3 www.ijesh.com ISSN: 2250 3552

change may have negative impacts on seeds, particularly in warm climates. Too hot temperatures can harm seed enzymes and affect seed sprouting. Seeds might sprout early in the warmer conditions, but fail to grow if watering is not done. Moisture is also a requirement for seed germination. The imbibition process is by which seeds absorb water. This activates enzymes and starts the growth of the embryo inside the seed. Climate change-induced irregular rainfall and droughts decrease the soil moisture. Seeds will not germinate well when soil is too dry. If germinating does start, seedlings can still die from lack of water. This decreases the number of plants and impacts vegetation regeneration. The timing of seed germination could also be affected by climate change. When temperature and moisture are right, many plants will start growing during a particular time of the year. The natural timing may be disrupted by changes in the seasons. Unseasonal rainfall would mean that seeds could germinate at an incorrect time, for instance. Seedlings could not survive if germination is followed by dry condition and/or high temperature. This impacts forests, grasslands and farmlands on the regeneration of plant species.

Seed dormancy may also be affected by climate change. Dormancy is the natural state of seeds that are not growing during the time they need to be. Not all seeds will germinate unless they receive cold temperature, rain, or some other seasonal cue. Climate change disrupts these signals and could interfere with the typical dormancy break process. This can decrease germination success of many wild plant species. In agricultural crops, low germination rates result in low establishment rates in the crop, uneven crop growth and lower harvests. Farmers may require re-sowing of seeds with additional cost and labour. In natural ecosystems, less germination will lead to less diversity in plants as there will be fewer seedlings. Rare and sensitive plant species are particularly vulnerable as they might already have few seed crops and have a reduced capacity for germination. Therefore, climate change impacts seed germination through temperature and moisture changes, seasonal shifts and changes in dormancy. Negative impacts at the germination stage can have a long-term impact on plants' life cycles and biodiversity as it is the base of their growth.

Impact of Climate Change on Plant Biodiversity

Climate change is particularly affecting plant biodiversity since plants are directly linked to temperature, rainfall, humidity, soil moisture, and seasonality. Biodiversity refers to the variety of life in nature and plant biodiversity refers to the variety of tree, herb, shrub, grass, climber, crop, medicinal and wild plant species. Rapid climate changes cause many plant species to fail to adapt to the new climate. This impacts on their growth, reproduction, distribution and survival. Climate change could lead to a decrease in the diversity of plant species in a habitat, disrupt natural habitats and endanger rare and sensitive plants. Biodiversity, or species diversity, is important in plants for ecological balance. Plants provide oxygen, food, medicine, timber, fibre and shelter to many organisms. They also help to prevent soil erosion, control water cycles, bind carbon dioxide and contribute to animal life. Insects, birds, microorganisms and human beings are impacted by climate

International Journal of Engineering, Science and Humanities
An international peer reviewed, refereed, open access journal
Impact Factor: 8.3 www.ijesh.com ISSN: 2250 3552

change's effect on plant biodiversity. Therefore, the impact of climate change on plant biodiversity is not limited to plants only, but it influences the whole ecosystem.

- **Concept and Importance of Biodiversity**

Biodiversity is the diversity of organisms on earth. Three levels of diversity are found in it: genetic diversity, species diversity and ecosystem diversity. The term genetic diversity refers to the differences in a given species, as in the different varieties of rice, wheat or mango. Species diversity is the diversity of plant and animal species in a given area. Ecosystem diversity refers to the diversity of ecosystems like forests, grasslands, wetlands, deserts, mountains and coastal areas. Biodiversity from a botanical point of view is the diversity of plant species and their variations present in various habitats. Biodiversity is very important due to its life supporting role. Biodiversity of plants plays a major part in ecological stability. In nature, various species of plants have various functions. Some plants are edible, some enrich the soil, some are for animal and insect shelter and some stop soil erosion.

Forests serve as a natural mechanism for controlling climate, by absorbing carbon dioxide, giving off oxygen. Wetland plants aid in water purification and grassland plants prevent erosion and support grazing animals. Therefore, biodiversity is responsible for maintaining the balance of natural systems. Biodiversity of plants is also essential for human beings. Numerous plants are utilized for food crops, fruits, vegetables, spices, fibres, oils and medicines. Traditional medicinal systems rely greatly on the species of plants. Many modern medicines are also derived from plants. Agricultural biodiversity is important as it enables farmers to adapt to the various climatic factors, pests and diseases. Crop wild relatives can be valuable for breeding new cultivars and varieties that are more useful and resistant to climate change. Climate change poses a risk to biodiversity when it alters the environmental factors that are essential for plant survival. Many species of plants are stressed when rainfall is irregular and droughts occur more often with increases in temperature. Limited adaptability species can diminish. Plants that are rare or endemic or connected to a specific habitat are more vulnerable as they may not be able to move to other locations. Hence, for ecological balance, food security, medicine, agriculture and future survival, protection of biodiversity is important.

- **Species Distribution Changes**

Species distribution is geographical area of natural occurrence of a given species of plants. Each species of plant has particular climate needs, including temperature, rain, sunlight, humidity and soil. Under these conditions, plants grow and reproduce well. Climate change can, however, modify these environmental conditions that results in redistribution of plant species. With increasing temperatures and shifting rainfalls, numerous plant species are being displaced to more favorable habitats. A big shift resulting from climate change is the shift of species to cooler areas. Many plant species are moving towards higher elevations in mountainous regions due to the warming of lower regions. Likewise, under some conditions, plants might shift their direction to

International Journal of Engineering, Science and Humanities
An international peer reviewed, refereed, open access journal
Impact Factor: 8.3 www.ijesh.com ISSN: 2250 3552

higher latitudes with a relatively colder climate. This is what plants do when it's a different temperature. But not all species of plants are mobile. Slow-growing plants and those that produce seeds, can have poor seed dispersal or special soil needs and may not move into new habitats.
Changes in species distributions can upset the balance of plant communities. New species, when introduced, can compete with native plants for water, nutrients, sunlight and space. Some species may grow faster in altered climate conditions, and dominate the ecosystem. This may decrease the amount of local flora. Climate change could accelerate the spread of invasive plants and their potential impact on native biodiversity. These changes affect an ecosystem's structure and composition. Mismatch can also occur between plants and other organisms due to climate change. For instance, if flowering time is altered by increasing temperatures, pollinator species like bees and butterflies may not be present at the appropriate time. This has an impact on pollination and seed production. Likewise, animals that rely on specific plants for food or shelter can be impacted if the distribution of these plants changes. Thus, the distribution of species is not only affected by the plants, but also by the whole of the ecological network. Climate change can cause a change in the climate space for crop cultivation in agricultural systems. The previous successful crops in a specific area could suffer reduced productivity with the heat and/or water stress. Farmers may need to shift to new crop varieties or new farming practices. Therefore, alteration of species distribution in the wild has great ecological, agricultural and economic implications.

- **Habitat Loss and Fragmentation**

Habitat is the natural environment in which a plant or animal lives, grows and reproduces. Habitat for plants is soil, water, temperature, sunlight, rainfall, and other organisms. Habitat loss means the destruction or degradation of natural habitats, while habitat fragmentation means the breaking of large, continuous habitats into smaller and isolated patches. Climate change is a significant driver of habitat loss and fragmentation due to its impact on the physical and biological characteristics of ecosystems. Habitat loss is a major consequence of climate change in many ways. Natural habitats may become unsuitable for plant growth due to rising temperature, drought, floods, sea-level rise, forest fires and irregular rainfall. For instance, extended droughts may lead to the drying of wetlands and to a decrease in water supply in forests and grasslands. Coastal vegetation and mangrove forests may be affected by sea-level rise. Frequent forest fires due to high temperature can destroy large areas of forest vegetation. If habitats are no longer suitable, plant species either decrease or disappear from the habitat.
Fragmentation is the process of breaking up continuous natural areas into smaller patches. Climate change exacerbates fragmentation by decreasing the quality of habitat that remains, although fragmentation is also caused by human activities like urbanization, agriculture, road construction and deforestation. Large populations of plants are not possible in smaller habitat patches. They also limit seed dispersal, pollination and genetic exchange among plant populations. This results in the isolation and genetic impoverishment of plant populations. Fragmented habitats are

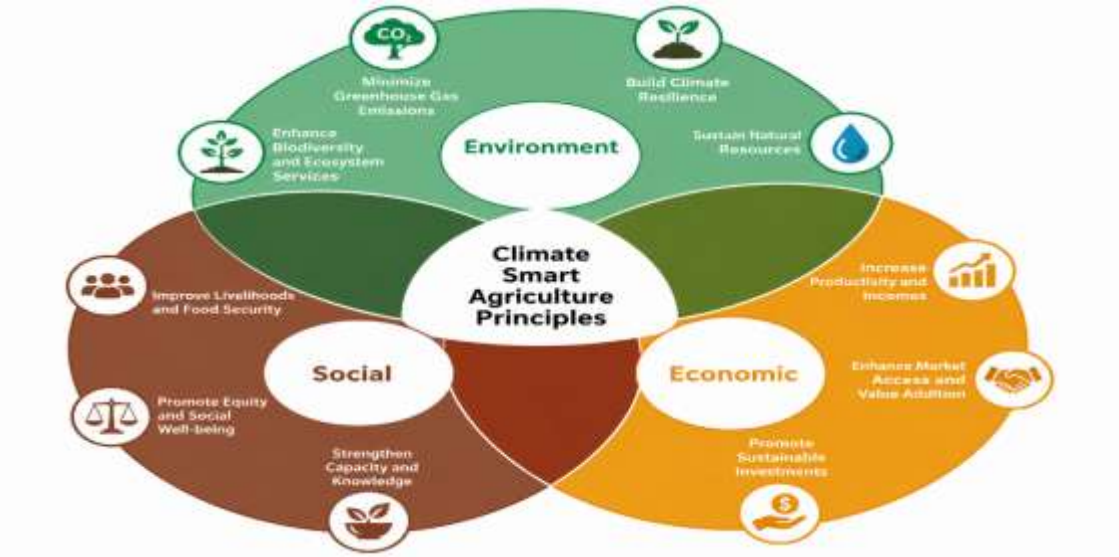
International Journal of Engineering, Science and Humanities
An international peer reviewed, refereed, open access journal
Impact Factor: 8.3 www.ijesh.com ISSN: 2250 3552

especially harmful for rare and endemic plant species. Endemic species are species that are only found in a specific area. Typically these plants are restricted in distribution and habitat. They may not survive if their habitat is destroyed or broken up. Diseases, pests, drought and other environmental stresses are more likely to affect small and isolated plant populations. This can result in local extinction over time. Loss and fragmentation of habitat also diminish ecosystem services. Forests, wetlands and grasslands offer valuable services like carbon sequestration, soil protection, water management and climate control. Loss and fragmentation of these habitats reduces their capacity to deliver these services. This further increases the negative effects of climate change. Therefore, climate change is a factor that leads to habitat loss and fragmentation through changes in temperature, precipitation, water availability and ecosystem stability. These changes lead to a decrease in plant biodiversity, a weakening of ecosystems and an increased risk of extinction. These impacts can be mitigated by conserving natural habitats, afforestation, protected areas, rehabilitation of degraded lands and sustainable land-use practices.

Climate Change and Ecosystem Dynamics

Climate change deeply affects ecosystem dynamics because ecosystems are formed by the interaction of plants, animals, microorganisms, soil, water and climate. In a natural ecosystem, temperature, rainfall, humidity, sunlight and seasonal patterns control the growth, reproduction and survival of living organisms. When these climatic conditions change, the balance of the ecosystem is disturbed. Climate change alters the structure, function and productivity of ecosystems. It affects plant communities, animal habitats, food chains, nutrient cycles, water cycles and species relationships. Since plants are primary producers, any change in plant growth or plant distribution directly influences the entire ecosystem. Therefore, climate change is not only a threat to individual species but also to the stability and functioning of whole ecosystems.

Image 3: Ecosystem-based Adaptation in Agriculture



International Journal of Engineering, Science and Humanities
An international peer reviewed, refereed, open access journal
Impact Factor: 8.3 www.ijesh.com ISSN: 2250 3552

This image explains the main principles of Climate Smart Agriculture through three important pillars: Environment, Social and Economic. The environmental pillar focuses on reducing greenhouse gas emissions, conserving biodiversity, protecting ecosystem services, building climate resilience and sustaining natural resources such as soil and water. These practices help agriculture adapt to climate change and reduce environmental damage. The social pillar highlights the importance of improving livelihoods, ensuring food security, promoting equity and strengthening farmers' capacity and knowledge.

It shows that climate-smart agriculture is not only about crop production but also about supporting farmers and rural communities. The economic pillar focuses on increasing productivity and income, improving market access, adding value to agricultural products and promoting sustainable investment. Overall, the image shows that climate-smart agriculture aims to balance environmental protection, social well-being and economic growth so that farming systems can become more sustainable, productive and resilient against climate change.

Changes in Forest Ecosystems

Forest ecosystems are one of the most valuable ecosystems on the earth. A wealth of trees, shrubs, herbs, climbers, fungus, insects, birds and animals can be found. Forests are able to control climate, help to wet the climate, are carbon sinks, protect the soil, support biodiversity, etc. Forest ecosystems are impacted in numerous ways by climate change. The normal growth and regeneration of forests are disturbed by rising temperature, irregular rains, drought, forest fire, pest attack, and alteration in the moisture of soil. Change in species composition is a significant effect of climate change on forests. All species of trees have a specific range of temperature, rainfall and soil moisture. Some species may not survive in their original habitat when the temperature increases or when it is uncertain whether any will rain. Species that are sensitive to heat and/or moisture may suffer, whereas drought-tolerant species could benefit. This alters the natural forests process. Forests may be made less dense and diverse, and become thinner, in some areas.

Forest regeneration is also impacted by climate change. Regeneration is the natural growth of new plants from seeds, seedlings or root sprout. Seeds require adequate soil moisture and soil conditions with a favourable temperature for successful regeneration. Seed germination and seedling survival could be reduced as a result of drought and high temperatures. Heat and water stress are more detrimental to young plants. If seedlings don't survive, the forest's self replenishment ability is reduced over time and the growth is weak. Another major issue related with climate change is forest fires. Forests are more susceptible to fire due to the increasing temperature and extended dry seasons. Dry leaves, branches and grasses are fuel, making the risk of fire spread greater. Forest fire harms the trees, seeds, soil organisms and wildlife habitat. They also contribute to the release of carbon dioxide to the atmosphere from the stored carbon dioxide, thereby contributing to global warming as well. This results in a vicious cycle of forest fires: climate change makes forest fires more likely, and forest fires make climate change more likely.

International Journal of Engineering, Science and Humanities
An international peer reviewed, refereed, open access journal
Impact Factor: 8.3 www.ijesh.com ISSN: 2250 3552

Climate change also makes forests more susceptible to pest and disease attacks. Many insects and pathogens can survive, reproduce and spread faster with warmer temperatures. Drought or heat stress weakens trees, making them more susceptible to disease. This can result in extensive tree death. Thus, forest ecosystems are sensitive to climate change and degradation will lower biodiversity, carbon storage and ecological balance.

Impact on Grassland Ecosystems

Grassland ecosystems consist of primarily grasslands, herbs and small shrubs. They provide habitat for grazers, insects, birds, soil organisms and numerous plants. Importance of grasslands for livestock, soil, carbon and biodiversity. Climate change impacts on the grassland ecosystems primarily affect temperature, precipitation, drought frequency and grazing pressure. Productivity and species composition of grasslands is highly sensitive to fluctuations in precipitation, so that small variations in precipitation can lead to large consequences. With the rising temperature, the moisture in the soil will decrease in the grasslands due to increased rate of evaporation. Grasses grow slowly and biomass is reduced when soil is dry. Biomass is all the plant matter that grows in a particular area. Grasses are an important food source for herbivores, and reduced biomass impacts them. When conditions are dry, some species of grass could be able to finish their life cycle rapidly or go dormant to survive. But, under repeated drought conditions, their survival and regeneration ability becomes diminished.

Climate change could also alter the species of plants in grassland. There are grasses which can withstand dry and hot conditions, and there are grasses which need more moisture. Climate stress could lead to the replacement of moisture-loving grasses by drought-tolerant ones. This leads to a decrease in plant species and alters grassland feeding value. Invasive plants and woody shrubs can invade grasslands in some instances. This process can result in the alteration of open grassland to shrub dominated habitat, which can decrease the habitat suitability for grassland animals and birds. Irregular rainfall has a strong effect on grassland ecosystems.

Heavy rainfall in a short time may lead to soil erosion and loss of nutrients, and long dry periods may lead to a loss of grass cover. Low grass cover allows soil to be exposed to wind and water erosion. Once soils become depleted of fertility, it is difficult to restore the grassland. It is particularly alarming in these semi-arid and arid areas, where grasslands are already facing threats due to overgrazing and land degradation. Grasslands also play an important role in carbon storage because their roots store carbon in the soil. Climate change can upset this carbon balance. Plant growth and root development could be reduced in drought and heat conditions, leading to carbon storage reduction. Under warmer conditions, soil respiration could increase, thus releasing additional carbon dioxide. Therefore, climate change will compromise the ecological services provided by grasslands, impacting not only on the biodiversity but also on climate regulation.

International Journal of Engineering, Science and Humanities
An international peer reviewed, refereed, open access journal
Impact Factor: 8.3 www.ijesh.com ISSN: 2250 3552

Climate Change and Agricultural Biodiversity

Climate change has a significant influence on agricultural biodiversity as it is directly dependent on climate, soil, water, temperature, precipitation and biological resources. Agricultural biodiversity is the diversity of plant, crop, animal and micro-organisms, their genetic resources and insects used in farming systems. It primarily refers to crop varieties, traditional seeds, wild relatives of crops, medicinal plants, fodder plants, soil organisms and plants depending on pollinators. This biodiversity is very important as it provides support to the continuity of agriculture in terms of its productivity, stability and adaptation to new environmental conditions. Agricultural biodiversity goes beyond the major crops – wheat, rice, maize, pulses and oilseeds.

It also encompasses local varieties, traditional crop species, fruit plants, vegetables, spices, medicinal plants, and wild plants that have medicinal and other useful applications for food and livelihood. Traditional crop varieties tend to be more tolerant of local climate, soil and water conditions. They might be tolerant of drought, flood, pests, diseases and high temperatures. Thus, agricultural biodiversity serves as a natural insurance system for the farmers for risks to climate change. The primary impacts of climate change on agricultural biodiversity include an increase in temperature, variability in rainfall, drought, flood, heat waves and changes to the seasonal cycle. Temperature and moisture requirements are needed for crop germination, vegetative growth, flowering, and fruiting and/or seed formation. If temperature exceeds the tolerance, the growth of crops weakens. Excessively high temperatures can affect the viability of pollen, fertilization and grain or fruit production. This results in lower germination and growth rate of the crop and poor seed quality. This is particularly bad for cereals, pulses and vegetables and fruit crops.

Another impact of climate change on agriculture biodiversity is irregular rain. The reliance of many crops on the rain, particularly in rain-fed farming regions. Uncertainty in rainfall makes it hard for farmers to make decisions about the appropriate crops and sowing date. Droughts lead to lower soil water availability and impact on seed germination, root growth and nutrient uptake. Excessive rain and floods can also cause damage to standing crops, carry away soil nutrients and destroy seeds. Crop diversity is also affected by such conditions as farmers may cease to grow crops that are sensitive or less profitable.

Traditional crop varieties and local seed systems are also at risk of climate change. In many parts of the world, farmers have bred and maintained their own varieties that are better adapted to their local environments. These are varieties of the heritage of agriculture and are rich in genetic characteristics. But with the changing climate, market pressure and the propagation of high yielding commercial varieties, traditional seeds are being lost. Without these varieties, there will be a loss of genetic diversity. This is risky as it is important that genetic resources of traditional varieties and crops wild relatives are available for future crop improvement. Crop wild relatives also play a significant role in the biodiversity of agriculture. They are wild plants that are closely related to cultivated plants. They can also be genetically modified to include resistance to drought,

International Journal of Engineering, Science and Humanities
An international peer reviewed, refereed, open access journal
Impact Factor: 8.3 www.ijesh.com ISSN: 2250 3552

heat, and pests and disease. The natural habitats of these wild relatives can be lost due to climate change. Losing these plants could result in the loss of valuable genetic resources for breeding climate-smart crops. Thus, conservation of wild relatives of crops is of great importance for future food security.

Soil biodiversity is also impacted by climate change, and is key for agriculture. The soil is full of bacteria, fungi, earthworms and lots of other microorganisms that aid in decomposition, nutrient cycling, nitrogen fixation, soil fertility, and more. Soil microbial activity can be decreased due to high temperatures, drought and chemical stress. As soil biodiversity decreases, so does soil fertility and plant growth is weakened. Good soil biodiversity is important in sustainable agriculture because it allows for the natural provision of nutrients and better crop yields. Other agricultural biodiversity components are pollinators. Fruit, vegetables, oilseeds and pulses are some of the crops that require pollination from bees, butterflies, and other insects. Pollinator-crop dynamics may be disrupted by climate change. Flowering time could be affected due to increased temperature and pollinator visiting time could not coincide. This incongruence decreases pollination efficiency and impacts fruit/seed production. Loss of pollinators has the potential to negatively impact agricultural production and biodiversity.

Climate change can also contribute to the spread of plant diseases, weeds and pests. Many insects, fungi and pathogens can persist and multiply more rapidly in warmer temperatures. New pests can be introduced to new regions where they have not previously occurred. These can be controlled with increased pesticide use by farmers, but excess pesticide use can adversely affect beneficial insects, soil organisms and general biodiversity in agriculture. Invasive weeds can also grow quickly and take over crops for water, nutrients and sunlight. Agricultural diversity is important to food security. A farming system with a variety of crops will be more stable than one relying on one or two crops. Crop failure from drought, heat or disease may not render other crops inedible or uneconomic, but rather valuable for food or income.

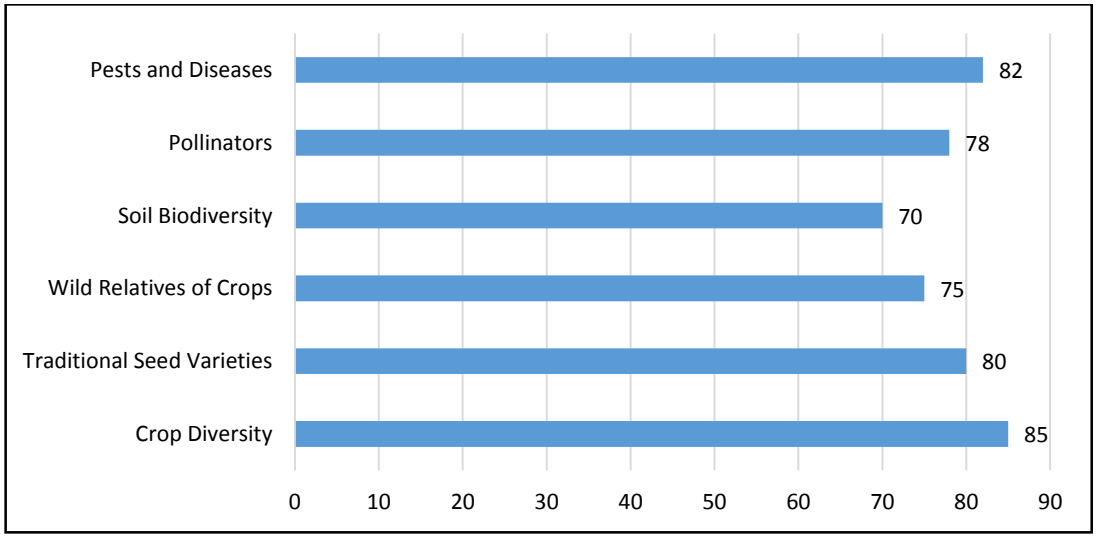
Diversifying crops also enhances nutrition because the different crops offer different nutrients. Hence, conservation and promotion of agricultural biodiversity is needed in the context of climate change with mixed cropping, crop rotation, organic agriculture, seed banks, traditional seed conservation and climate resilient agriculture. Hence, it is able to say that climate change has a close relationship with agricultural biodiversity. Crops diversity, traditional seeds, soil organisms, pollinators and wild plant resources are at risk due to climate change. Meanwhile, agriculture offers solutions for climate adaptation in the form of biodiversity. Preserving locally adapted varieties, sustainable agriculture, cultivation of wild relatives of crops and the creation of climate-smart varieties are key to ensuring the productivity and ecological balance of agriculture in the future.

International Journal of Engineering, Science and Humanities
An international peer reviewed, refereed, open access journal
Impact Factor: 8.3 www.ijesh.com ISSN: 2250 3552

Table 2: *Climate Change and Agricultural Biodiversity*

S. No.	Agricultural Biodiversity Component	Impact of Climate Change	Value (%)
1	Crop Diversity	Rising temperature and irregular rainfall reduce crop variety and productivity	85
2	Traditional Seed Varieties	Heat and drought reduce the use and survival of local seed varieties	80
3	Wild Relatives of Crops	Habitat change threatens wild crop species and useful genetic resources	75
4	Soil Biodiversity	High temperature and drought reduce soil microorganisms and fertility	70
5	Pollinators	Change in flowering time affects bees, butterflies and pollination process	78
6	Pests and Diseases	Warmer climate increases pest attacks and plant diseases	82

Figure 1: *Climate Change and Agricultural Biodiversity*



The table below provides an explanation of the effects of climate change on various aspects of agricultural biodiversity. The table shows that the influence is largest on crop diversity, which is

International Journal of Engineering, Science and Humanities
An international peer reviewed, refereed, open access journal
Impact Factor: 8.3 www.ijesh.com ISSN: 2250 3552

85%. The change in temperature and irregular rainfall decreases the diversity of crops and impacts crop productivity. In the event of non-optimal climatic conditions, many species and varieties of crops suffer from poor growth, thereby reducing the variety of crops. 80% is the impact on traditional seed varieties. Local seed varieties are not used and do not survive due to heat stress and change in rainfall. The significance of these traditional seeds lies in their ability to maintain the genetic diversity and enable farmers to adjust to local environmental conditions. Likewise, 75% of wild relatives of crops are affected by habitat change and climate stress. Wild species are sources of valuable genetic resources for developing climate-resistant crops. The table also reveals that 70% is also impacting soil biodiversity. Microorganisms, earthworm, and other organisms in the soil that are responsible for soil fertility are decreased by high temperature and drought. 78% affects pollinators by disrupting the flowering time cycle between plants and pollinators like bees and butterflies. Finally, the impact value for pests and diseases is 82%. Increased pests attack and crop diseases due to warmer climatic conditions pose additional risk to crop production and sustainable agriculture. In general, the table indicates that agriculture biodiversity is strongly impacted by climate change and poses significant challenges for food security.

Conclusion

Plants are highly vulnerable to the effects of climate change. Increasing temperature, variability in precipitation, droughts and floods, as well as heat waves and altered seasonal rains disrupt plant growth. These changes impact on seed germination, root and shoot growth, photosynthesis and respiration, flowering, fruiting and seed formation. Consequently, productivity of plants is lowered and many species become weak and cannot withstand changing environmental conditions. Climate change poses additional risks for plant biodiversity through habitat loss, habitat fragmentation, plant migration and the extinction of rare and endemic plant species. Climate Change is also a major determinant of agricultural biodiversity. Traditional seeds, wild relatives of crops, soil organisms and pollinators are affected by heat, drought, unusual precipitation patterns, and more pests. This poses significant problems for food security, agriculture and sustainable farming. Biodiversity, however, is an important solution to climate change in that diverse crops, local seeds and wild genetic resources can facilitate adaptation to changing conditions. Hence, preserving plant diversity, conserving natural habitats, afforestation, preserving seed and gene banks and developing climate resilient crops are important. Protecting plant life, maintaining ecological balance and creating a healthy future for future generations, sustainable agriculture and collective environmental efforts are crucial.

References

1. Ainsworth, E. A., & Long, S. P. (2005). What have we learned from 15 years of free-air CO_2 enrichment? A meta-analytic review of the responses of photosynthesis, canopy properties and plant production to rising CO_2. *New Phytologist, 165*(2), 351–371.

2. Bellard, C., Bertelsmeier, C., Leadley, P., Thuiller, W., & Courchamp, F. (2012). Impacts of climate change on the future of biodiversity. *Ecology Letters, 15*(4), 365–377.
3. Bita, C. E., & Gerats, T. (2013). Plant tolerance to high temperature in a changing environment: Scientific fundamentals and production of heat stress-tolerant crops. *Frontiers in Plant Science, 4*, 273.
4. Challinor, A. J., Watson, J., Lobell, D. B., Howden, S. M., Smith, D. R., & Chhetri, N. (2014). A meta-analysis of crop yield under climate change and adaptation. *Nature Climate Change, 4*(4), 287–291.
5. Dawson, T. P., Jackson, S. T., House, J. I., Prentice, I. C., & Mace, G. M. (2011). Beyond predictions: Biodiversity conservation in a changing climate. *Science, 332*(6025), 53–58.
6. Food and Agriculture Organization of the United Nations. (2013). *Climate-smart agriculture sourcebook*. FAO.
7. Food and Agriculture Organization of the United Nations. (2019). *The state of the world's biodiversity for food and agriculture*. FAO.
8. Hatfield, J. L., & Prueger, J. H. (2015). Temperature extremes: Effect on plant growth and development. *Weather and Climate Extremes, 10*, 4–10.
9. Intergovernmental Panel on Climate Change. (2021). *Climate change 2021: The physical science basis*. Cambridge University Press.
10. Intergovernmental Panel on Climate Change. (2022). *Climate change 2022: Impacts, adaptation and vulnerability*. Cambridge University Press.
11. IPBES. (2019). *Global assessment report on biodiversity and ecosystem services*. Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services.
12. Jump, A. S., & Peñuelas, J. (2005). Running to stand still: Adaptation and response of plants to rapid climate change. *Ecology Letters, 8*(9), 1010–1020.
13. Lal, R. (2004). Soil carbon sequestration impacts on global climate change and food security. *Science, 304*(5677), 1623–1627.
14. Lesk, C., Rowhani, P., & Ramankutty, N. (2016). Influence of extreme weather disasters on global crop production. *Nature, 529*(7584), 84–87.
15. Lobell, D. B., & Field, C. B. (2007). Global scale climate–crop yield relationships and the impacts of recent warming. *Environmental Research Letters, 2*(1), 014002.
16. Lobell, D. B., Schlenker, W., & Costa-Roberts, J. (2011). Climate trends and global crop production since 1980. *Science, 333*(6042), 616–620.
17. Memmott, J., Craze, P. G., Waser, N. M., & Price, M. V. (2007). Global warming and the disruption of plant–pollinator interactions. *Ecology Letters, 10*(8), 710–717.
18. Ollerton, J., Winfree, R., & Tarrant, S. (2011). How many flowering plants are pollinated by animals? *Oikos, 120*(3), 321–326.

International Journal of Engineering, Science and Humanities
An international peer reviewed, refereed, open access journal
Impact Factor: 8.3 www.ijesh.com ISSN: 2250 3552

19. Parmesan, C. (2006). Ecological and evolutionary responses to recent climate change. *Annual Review of Ecology, Evolution and Systematics, 37*, 637–669.
20. Parmesan, C., & Hanley, M. E. (2015). Plants and climate change: Complexities and surprises. *Annals of Botany, 116*(6), 849–864.
21. Parmesan, C., & Yohe, G. (2003). A globally coherent fingerprint of climate change impacts across natural systems. *Nature, 421*(6918), 37–42.
22. Peñuelas, J., & Filella, I. (2001). Responses to a warming world. *Science, 294*(5543), 793–795.
23. Potts, S. G., Biesmeijer, J. C., Kremen, C., Neumann, P., Schweiger, O., & Kunin, W. E. (2010). Global pollinator declines: Trends, impacts and drivers. *Trends in Ecology & Evolution, 25*(6), 345–353.
24. Rosenzweig, C., Karoly, D., Vicarelli, M., Neofotis, P., Wu, Q., Casassa, G., Menzel, A., Root, T. L., Estrella, N., Seguin, B., Tryjanowski, P., Liu, C., Rawlins, S., & Imeson, A. (2008). Attributing physical and biological impacts to anthropogenic climate change. *Nature, 453*(7193), 353–357.
25. Thuiller, W., Lavorel, S., Araújo, M. B., Sykes, M. T., & Prentice, I. C. (2005). Climate change threats to plant diversity in Europe. *Proceedings of the National Academy of Sciences, 102*(23), 8245–8250.