Journal of Agriculture, Environmental Resource and Management
ISSN2245-1800(paper) ISSN 2245-2943(online)
4(1)99-104; Dec.2019

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# Climate Change, Plant Diseases And The Challenge Of Food Security

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**Abstract**

*Climate change is driven by global warming which in itself is largely a result of the greenhouse effect. The greenhouse effect arose from the depletion of the protective ozone layer in the atmosphere and has been driven by anthropogenic activities. The period from 1983- 2012 have been the warmest 30-year period of the last 1400 years. Global temperature over the earth's surface has increased by 0.85$^0$C from 1880 – 2012. Over the period from 1901 – 2010, global mean sea-level rose by 0.19m. Population size, economic activities involving fossil fuel consumption and industrialization, land-use patterns and life-style have combined to drive up $CO_2$ emissions. Climate change is having and is predicted to have significant impact on food security. Global temperature rises combined with increasing food demand are expected to pose significant risk to food security globally. Global warming is expected to impact Africa in several ways including reduction in crop and animal yields. Projected sea-level rise will affect low-lying areas with large populations. The cost of adaptation and mitigation in affected countries could cost up to 5-10% of GDP. By 2080, African arid and semi-arid land is expected to increase by 5-8%. The projected impact on agriculture, forestry and the ecosystem include increased disease and insect outbreaks, lower yields, soil erosion, increase danger of wild-fires and salinization of fresh water bodies. These negative impacts will affect food security. Climate change affects the level of yield losses due to plant pathogens. The major factors of climate – temperature, $CO_2$, moisture, light and wind- play major roles in the levels of incidence and severity of plant pathogens.*

**Keywords: Climate change, greenhouse effect, anthropogenic, food security, plant diseases**

## Introduction

### Definition

Climate change refers to a change in the state of the climate that can be identified (using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity

(IPCC, 2007). The United Nations Framework Convention on Climate Change (UNFFCCC), defines climate change as a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods.

**Global warming and The Greenhouse Effect**

Climate change is caused by global warming which in itself is caused by the greenhouse effect. The phenomena of global warming and the precursor greenhouse effect is illustrated in fig. 1. Approximately half of radiation from the sun, reaches the earth and is absorbed, warming the earth in the process. Some of this heat from the earth is emitted as infrared radiation which is absorbed by greenhouse gases and the clouds and reemitted in all directions warming the lower atmosphere and the earth's surface. This warming effect is known as the greenhouse effect.

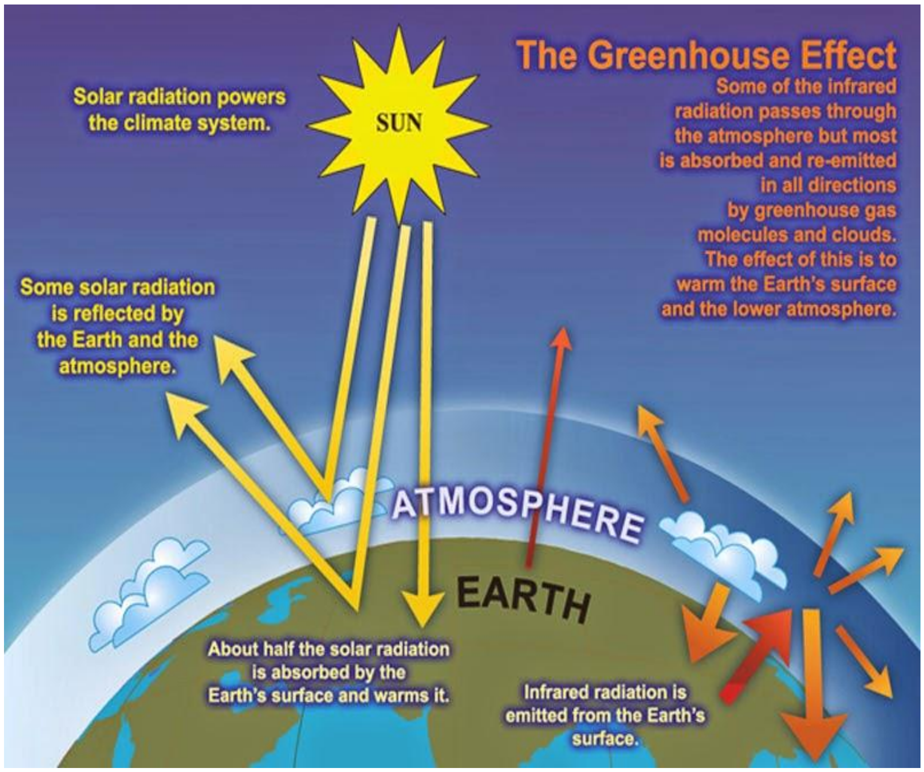



**Fig. 1: The development of the Greenhouse effect**

**The Earth's atmosphere**

The atmosphere surrounding the earth is divided into 4 layers (fig. 2) which are characterized by differences in chemical composition, which in turn produce differences in temperature in the different layers. The 4 layers of the atmosphere are: the troposphere, the stratosphere, the mesosphere and the thermosphere. The troposphere is the layer closest to the earth and is exists up to about 10km above the earth. It is about 80% of the mass of the atmosphere and has a high density of air. The stratosphere rises to about 50km above the earth and heats up mainly because of the absorption of ultra-violet (UV) radiation by ozone in this layer. The mesosphere rises up to 80km above the earth's surface where temperatures can reach 190K. The mesosphere is the coldest part of the atmosphere. The thermosphere rises up to 100km above the earth and its temperatures can reach up to $2000^0$C because of the absorption of shortwave UV-radiation by few molecules of molecular oxygen and nitrogen that are found in this zone.

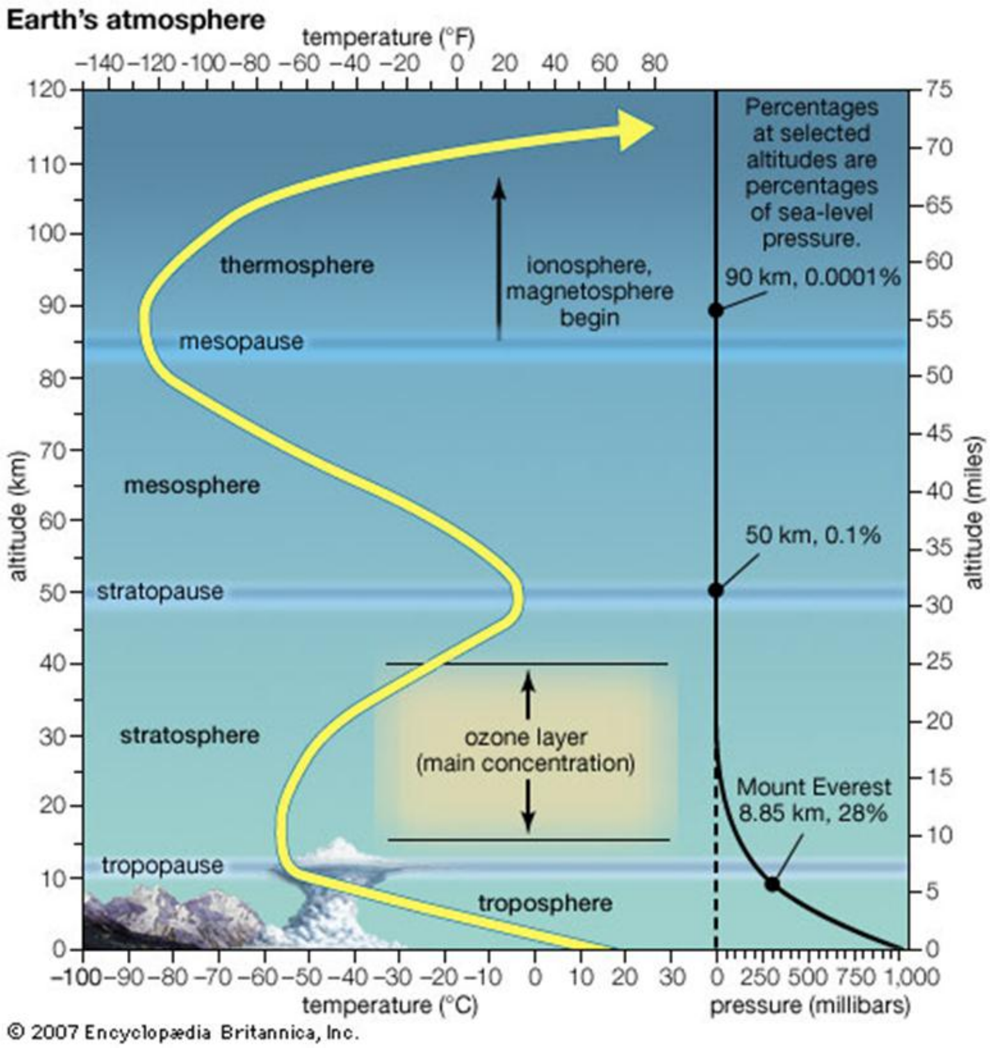



**Fig. 2: Layers of the earth's atmosphere**

The gaseous composition of the lower atmosphere is shown in Table 1. The most important of these gases are Nitrogen, Oxygen, Water vapour, Carbon dioxide, Methane, Hydrogen, Nitrous oxide and Ozone. Nitrogen and Oxygen make up 99% of the gaseous composition. Nitrogen is important for plant nutrition while Oxygen is important in photosynthesis and respiration.

| Gas Name | Chemical formula | Percent volume |
|---|---|---|
| Nitrogen | $N_2$ | 78.08 |
| *Oxygen | $O_2$ | 20.95 |
| Water | $H_2O$ | 0-4 |
| Argon | Ar | 0.93 |
| *Carbon dioxide | $CO_2$ | 0.0360 |
| Neon | Ne | 0.0018 |

| | | |
|---|---|---|
| Helium | He | 0.0005 |
| *Methane | $CH_4$ | 000017 |
| Hydrogen | $H_2$ | 000005 |
| *Nitrous Oxide | $N_2O$ | 000003 |
| *Ozone | $O_3$ | 0.000004 |
| *Halocarbons | $CFCl_3$, $CF_2Cl_2$ | 000000008 |

*variable gases

**Table 1. Average composition of the atmosphere up to 25km (***Source: University of Oslo, 2009***)**

Lightning can cause Nitrogen and Oxygen to combine to form Nitrogen oxides which are very reactive.

**Water vapour** is important because:

- It redistributes heat energy through latent heat exchange via evaporation and condensation
- Its condensation creates precipitation that falls on the earth's surface and in the process provides water for plants and animals
- It helps warm the earth's atmosphere through the Greenhouse

**Carbon dioxide** is important because it is required for the life processes of photosynthesis and respiration.

**Ozone**

***Ozone is found mainly in the stratosphere and it is important because it absorbs most of the harmful UV- radiation from the sun. It also acts as a greenhouse gas.***

**Formation of Ozone**

Molecular oxygen is very stable and is present in large amounts (21% by volume) in the atmosphere. Ozone can be formed when atomic oxygen reacts with ordinary molecular oxygen. The reaction takes place in a two-step process according to the following reaction scheme:

$$O_2 + hv \rightarrow O + O$$

$$O + O_2 \rightarrow O_3 + M$$

***hv represents photons of UV radiation***

***M is a reaction partner like Nitrogen molecule which acts as a catalyst and is not used or modified***

Ozone may also be formed in the troposphere when oxygen is released from nitrogen dioxide ($NO_2$) by photolysis. The energy required is less than the energy required for the splitting of the oxygen molecule. In large cities with a lot of traffic photochemical smog (containing e.g. NO, $NO_2$ and ozone) is formed. A smog episode often starts with the release of NO-gas from cars or generators. The gas is then oxidized to $NO_2$. When the $NO_2$-molecule is exposed to sunlight an oxygen atom may be released and ozone is formed. The process can be described by the following reaction sequence:

$$2NO + O_2 \rightarrow 2NO$$

$$NO_2 + hv \rightarrow NO + O$$

$$O + O_2 + M \rightarrow O_3 + M$$

The halogens (chlorine, bromine and fluorine and iodine) are involved in the formation and destruction of ozone.

Other compounds involved in the destruction of ozone are the nitrogen oxides, water radicals, halogens and halocarbons in the atmosphere

Radiation from the sun plays an important part in the formation and destruction of ozone.

**Ozone is important because it protects life on earth from the harmful radiation from the sun** (University of Oslo, 2009).

**Consequences of the greenhouse effect**

According to IPCC (2014), the warming of the climate is unequivocal. It noted that each of the last three decades have been progressively warmer than the preceding decade since 1850 and that the period from 1983 to 2012 have been the warmest 30-year period of the last 1400 years. The global temperature over the earth's surface has increased by $0.85^{0}C$ from 1880 to 2012. Also, over the period 1901 - 2010, global mean sea level rose by 0.19m. Anthropogenic greenhouse gases (GHGs) and other factors have been implicated and appear likely to be the cause of the increased warming of the earth's surface. Emissions of these anthropogenic GHGs have been implicated in the large increases in the atmospheric concentrations of carbon dioxide ($CO_2$), methane ($CH_4$), and nitrous oxide ($N_2O$). About 40% of these emissions have remained in the atmosphere while the rest was removed from the atmosphere and stored on land (in plants and soils) and in the ocean. The ocean has absorbed about 30% of the emitted anthropogenic $CO_2$, causing ocean acidification. About half of the anthropogenic $CO_2$ emissions between 1750 and 2011 have occurred in the last 40 years. Emissions of $CO_2$ from fossil fuel combustion and industrial processes contributed about 78% of the total GHG emissions increase from 1970 to 2010, with a similar percentage contribution accounting for the increase during the period 2000 to 2010. Globally, population size, economic activity, lifestyle, energy use, land-use patterns, technology and climate policy are the most important drivers of increases in $CO_2$ emissions from fossil fuel combustion.

Climate change was projected to undermine food security (IPCC, 2014). Due to projected climate change by the mid-21st century and beyond, global marine species redistribution and marine biodiversity reduction in sensitive regions was expected to affect the sustained provision of fisheries. For wheat, rice and maize in tropical and temperate regions, climate change without adaptation was projected to negatively impact production. Global temperature increases of about 4°C or more above late 20th century levels, combined with increasing food demand, was expected to pose large risks to food security globally. Climate change was projected to reduce renewable surface water and groundwater resources in most dry subtropical regions, intensifying competition for water among sectors. An example is the Lake Chad that is gradually disappearing as shown in fig. 3.

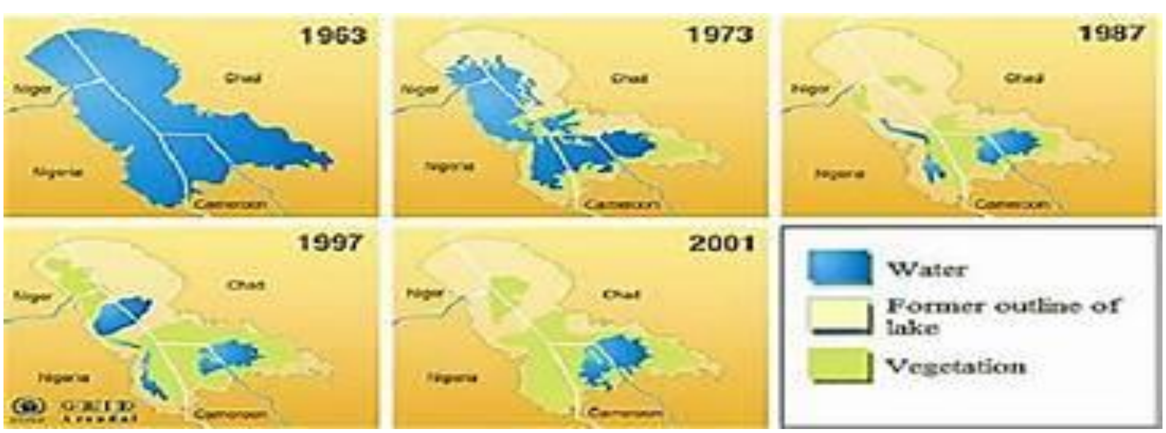



**Fig. 3 The disappearing Lake Chad (1963-2001)**
**Source: www.researchgate.org**

IPCC (2007) had stated as follows:

- Global GHG emissions due to human activities have grown since pre-industrial times, with an increase of 70% between 1970 and 2004
- Carbon dioxide ($CO_2$) is the most important anthropogenic GHG. Its annual emissions grew by about 80% between 1970 and 2004.
- Global atmospheric concentrations of $CO_2$, methane ($CH_4$) and nitrous oxide ($N_2$ O) have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years
- Atmospheric concentrations of $CO_2$ (379ppm) and $CH_4$ (1774ppb) in 2005 exceed by far the natural range over the last 650,000 years.
- Global increases in $CO_2$ concentrations are due primarily to fossil fuel use, with land-use change providing another significant but smaller contribution. It is very likely that the observed increase in $CH_4$ concentration is predominantly due to agriculture and fossil fuel use
- **Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic GHG concentrations.**

The projected impact of these temperature changes in Africa were:

- By 2020, between 75 and 250 million of people are projected to be exposed to increased water stress due to climate change.
- By 2020, in some countries, yields from rain-fed agriculture could be reduced by up to 50%.
- Agricultural production, including access to food, in many African countries is projected to be severely compromised.
- This would further adversely affect food security and exacerbate malnutrition.
- Towards the end of the 21st century, projected sea level rise will affect low-lying coastal areas with large populations. The cost of adaptation could amount to at least 5 to 10% of Gross Domestic Product (GDP).
- By 2080, an increase of 5 to 8% of arid and semi-arid land in Africa is projected under a range of climate scenarios

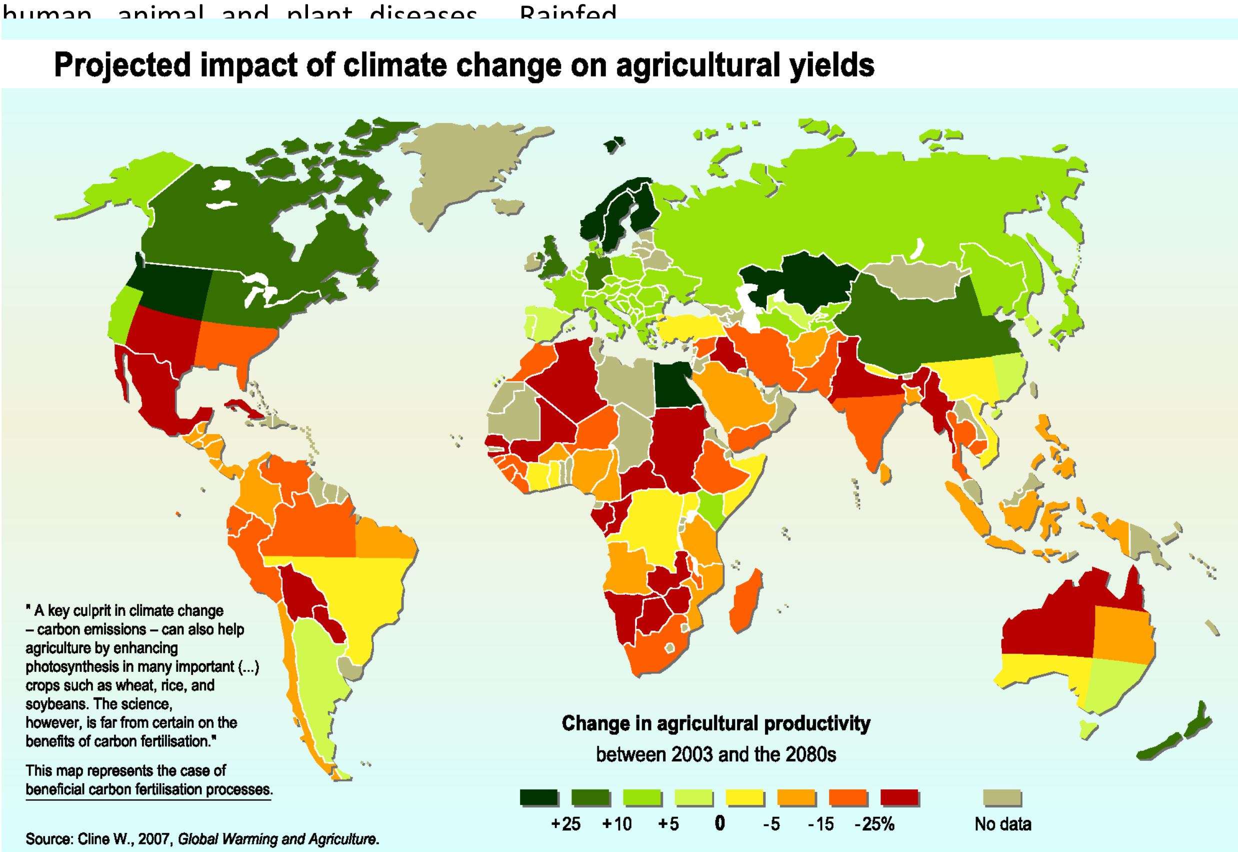
The projected impact on agriculture, forestry and the ecosystem were:

- Decreased yields in warmer environments
- Increased insect outbreaks
- Reduced yields in warmer regions due to heat stress
- Increased danger of wildfires
- Soil erosion
- Inability of cultivate land due to waterlogging
- Land degradation
- Crop failure, crop damage and lower yields
- Increased death of livestock
- Uprooting of trees
- Salinization of fresh water systems, estuaries and irrigation water

**Food Security**

The World Food Summit of 1996 defined ***food security*** as existing when all people at all times have access to sufficient, safe, nutritious food to maintain a healthy and active life.

Food production is highly sensitive to climate change mainly with respect to rainfall and temperature which are the main factors that determine the global distribution of food crops. Climate change leads not only to greater variability in rainfall and temperature but increase in the likelihood of occurrence of extreme events like drought, floods and heat waves. A changing climate is associated with increased threats to food safety, post-harvest losses and pressure from invasive species, pests and diseases. Already heightened by increased global movement of goods and people, a warming climate is likely to increase the incidence and geographic spread of human, animal and plant diseases. Rainfed and pastoral agriculture are very susceptible to changes in climate and in some locations global warming may cause flooding and in other locations may make the drought situation more acute. Global warming may also lead to shorter growing seasons in Africa and as shown in fig. 4, will have an adverse effect on food production in the continent (Beddington et. al., 2012).




Plant diseases are of great importance to humans because of their negative impact resulting from the losses they cause of plants and products derived from plants. Losses may be in the form of direct loss of yield of crops or of products that man utilizes for food, clothing, furniture and environmental aesthetics, as follows:

Direct loss of yield of crops can lead to extreme conditions like mass starvation as occurred in

- Ireland in 1845 – 1846.
- Direct loss of yield may lead to massive losses of national income by countries in cases where agricultural produce constitutes the major foreign exchange earner like with Groundnuts and Cocoa in Nigeria.
- Diseases attacking trees may impact the type of industries that can exist in a country.
- Losses may be due to the poisoning effect of plant pathogens on plant produce. For example, cereal and legume grains and other farm products are often contaminated by secondary metabolites secreted by fungi. These metabolites are often toxic and are known as mycotoxins. In Nigeria, the major mycotoxin contaminating agricultural produce and by-products are Aflatoxins produced by *Aspergillus spp.* , Fumonisins produced by *Fusarium spp.*, Trichothecenes also produced by *Fusarium spp.* and Ochratoxins produced by various species of *Aspergillus* and *Penicillium.* (Adejumo and Adejoro, 2014).

According to the disease triangle (fig 5), for disease to occur, three factors of susceptible host, causal agent and a favourable environment must occur simultaneously. The major factors of the environment that are important in disease development are temperature and rainfall (amount, timing and source), wind and light intensity or shade. Other environmental factors relate to the soil (drainage, soil type, pH, fertility and nature of fertilizer applied), and to nature of chemicals (insecticides, fungicides and herbicides) used on the crop.


**Fig. 5 The Disease Triangle**

**Effect of environment on plant disease**

Changes in environmental conditions affect the level of losses because environment exerts significant effects on pathogens and their host plants. Changes associated with global warming such as elevated temperatures, increased levels of $CO_2$ and Ozone can affect the incidence and severity of diseases in plants. I will examine the effects of these major elements of climate change on some plant pathogens and the diseases they cause.

**Effect of Elevated temperatures**

- Yanez- Lopez et. al. (2012) reviewed the effect of climate change on plant diseases and noted that due to changes in temperature and precipitation regimes, climate change may alter the growth stage, development rate and pathogenicity of infectious agents, and the physiology and resistance of the host plant. They suggested that sunlight affects pathogens due to the accumulation of phytoalexins or protective pigments in host tissue and a change in temperature may favor the development of different inactive pathogens, which could induce an epidemic. Increase in temperatures with sufficient soil moisture may increase evapotranspiration resulting in humid microclimate in crop and may lead to incidence of diseases favored under these conditions.

- Temperature is one of the most important factors affecting the occurrence of bacterial diseases caused by pathogens such as *Ralstonia solanacearum, Acidovorax avenae* and *Burkholderia glumea.*
- Similarly, the incidence of vector-borne diseases could be altered. Climate can substantially influence the development and distribution of vectors. Changes may result in geographical distribution, changes in population growth rates, increases in the number of generations, extension of the development season, changes in crop-pest synchrony of phenology, changes in interspecific interactions and increased risk of invasion by migrant pests. Because of the short life cycles of insects, mobility, reproductive potential, and physiological sensitivity to temperature, even modest climate change will have rapid impacts on the distribution and abundance of vectors. Thus, increase in temperature may be result in high rates of development of insects, obtaining a greater number of insect generations per cycle (Yanez-Lopez et. al., 2012)
- Huot et. al. (2017) showed that elevated temperatures significantly affect the susceptibility of *Arabidopsis* to *Pseudomonas syringae pv. tomato (Pst*) DC3000 and affects the biosynthesis of Salicylic acid which is important in plant defense against pathogens.
- Temperature may alter the growth stage, development rate and pathogenicity of infectious agents. (Charkraborty et.al., 1998)
- Increase in temperatures with sufficient soil moisture may increase evapotranspiration resulting in humid microclimate in crop and may lead to incidence of foliar diseases favored under these conditions
- Increased aggressiveness at higher temperatures of stripe rust isolates (Puccinia striiformis), (Mboup et.al., 2012)
- lignification of cell walls increased in forage species at higher temperatures to enhance resistance to fungal pathogens

**Effect of elevated $CO_2$ levels**

- An increase in $CO_2$ levels may encourage the production of plant biomass.

  This assertion is derived from the dynamics of the equation that defines the process of photosynthesis by which plants use sunlight to synthesize food from carbon dioxide and water using the green pigment, chlorophyll, and producing Oxygen as an end-product.

  $$\mathbf{6CO_2 + 12H_2O + Light \rightarrow C_6H_{12}O_6 + 6H_2O + 6O_2}$$

  **Carbon dioxide Water Glucose Water Oxygen**

  An increase in the concentration of carbon dioxide will lead to the production of more glucose and distribution to the rest of the plant. The net effect will be production of more biomass.
- The subsequent dense canopy favors the incidence of rust, powdery mildew, *Alternaria* blight, *Stemphylium* blight and anthracnose diseases

- High disease incidence and severity due to changes in host,
- Reduced stomatal opening and changes in leaf chemistry. In such situations, diseases caused by the pathogens that infect through stomata such as *Phyllosticta minima* may be reduced (McElrone et. al.,2005)
- Studies on *Colletotrichum gloeosporioides* at atmospheric $CO_2$ concentrations of 350 and 700 ppm on susceptible *Stylosanthes scabra* in a controlled environment showed that many lesions per plant were produced under high $CO_2$, because the enlarged canopy trapped more spores (Pangga et al., 2004)
- Studies on interactions between *Erysiphe cichoracearum* and *Arabidopsis thaliana* under elevated levels of $CO_2$ showed that more colonies were produced on mature leaves (Lake and Wade (2009)

1. Studies on the effect of $CO_2$ and $O_3$ on three soybean diseases (downy mildew, *Septoria* and sudden death syndrome) in the field showed reduced downy mildew disease severity but increased brown spot severity and no effect in sudden death syndrome. (Eastburn et al., 2010)
2. Studies on the effects of elevated $CO_2$ and temperature on the incidence of major chili pepper diseases, anthracnose, *Phytophthora* blight showed that anthracnose decreased and *Phytophthora blight* slightly increased (Shin and Yun (2010)

**Effect of moisture**

- Helps in the activation of bacterial, fungal and nematode pathogens
- Distribution and spread of many pathogens on the same plant and from plant to plant in the same field or to other fields
- Affects fungal spore germination, formation and longevity
- Late blight of potato, downy mildew and other diseases are more severe in areas of high rainfall or high relative humidity
- Many soil pathogens (e.g Phytophthora and Rhizoctonia) and some bacteria (Erwinia, Pseudomonas) and most nematodes usually cause their most severe symptoms on plants when soil is wet but not flooded
- Excess soil moisture favours soil-borne diseases caused by *Phytophthora, Pythium, Rhizoctonia solani* and *Sclerotium rolfsii*

**Effect of wind**

- Important for the dispersal of inoculum
  Wind causes injury to plants and facilitates infection by fungi, bacteria and mechanically transmitted viruses
- Sometimes helps to reduce infection by drying wet surfaces on which fungi and bacteria inoculum have landed

**Effect of light**

- The intensity and duration of light may increase or decrease the susceptibility of plants to infection and also affect severity of infection
- Decreased light intensity increases the susceptibility of plants to virus infection

**Conclusion**

In summary, climate influences all stages of development of host and pathogen. Temperature, water and light are the major factors affecting growth and development of hosts and pathogens. Climate influences incidence and severity of various plant diseases. Climate plays a major role in dispersal of inoculum and consequently in spread of diseases. Climatic factors of temperature, $CO_2$ concentration, water, humidity and wind play major roles in the survival, rate of multiplication, sporulation in fungi and bacteria, rate of spore germination, ease of penetration into the host, distance of dispersal of inoculum and vigour of pathogen and host.

Environmental changes would add to the unpredictability of these events and could create the conditions for unpredictably high incidence and severity of various plant diseases.

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