

## Minireview Article

# "The Impact of Climate Change on Wheat Productivity: Current Trends and Future Challenges"

### **Abstract**

Climate is the average of weather situation in a particular area, which affects all parts of ecosystem. Due to industrialization and urbanization, forests are cutting down and converted into living societies. This change in ecosystem disturbs the balance of ecosystem from decomposers to producers and consumers. Important part of ecosystem is plants (producers) that are energy providers. This alteration affects productivity and sustainability of plants. Wheat is staple food, which is highly affected by temperature and CO<sub>2</sub> elevation. It not only affects wheat yield but also make wheat vulnerable to several diseases. High temperature causes a high rate of transpiration, which causes drought that ultimately leads to low productivity. A model was designed on drought conditions and result showed that global warming causes serious drought in 60 % of wheat growing areas of the world. Currently, drought affects 15 % of wheat productivity. It was predicted that every 2° C shift of temperature can cause severe water shortage in the coming 20 to 30 years. Water shortage at milking and grain filling stage will affect yield. This article includes factors affecting climate, impact on wheat growth, yield, and elevation of carbon dioxide, impact on disease severity, prediction model for temperature rise, and CO<sub>2</sub> curve in 2050.

**Keywords** - Ecosystem, Productivity, Drought, Warming.

### **Introduction**

Long-term change in the weather pattern is affected by natural and human factors. Climate is changing every day due to several natural processes as well as by human acts. One of the biggest sources of climate change is the accumulation of carbon dioxide in our atmosphere. Carbon dioxide accumulates in the atmosphere by burning fossil fuel, automobile smoke, chlorofluorocarbons released from electric appliances (air conditions or refrigerators), and volcanic eruptions. Humans release carbon dioxide into the air during respiration. Accumulation of carbon dioxide in an atmosphere enhanced the greenhouse effect because carbon dioxide is considered one of the most important gases in greenhouse gases. It is observed that amount of carbon in the atmosphere is 80% increases today from the time when life on earth started. The main reason for this increased value is humans. In past released carbon was utilized by plants as it is the main element in photosynthesis. But with the passage of time human population increases and agricultural land is being utilized by humans for shelter. With the advancement of colonization deforestation started and agricultural land or cultivated land turned into housing societies. Carbon dioxide released from automobile vehicles accumulates in the air [1]. Other gases include methane, Nitrous oxide, Ozone, Water vapor, Halocarbons. These gases create a sheet around the earth. This sheet is denser in the northern hemisphere because of extreme cold they use more fossil fuels. This sheet of gases causes a rise in temperature on earth also known as global warming. These two terms are inter-related. This temperature rise not only affects humans but also disturbs all the

natural habitats and ecosystems on earth. Climate change effects not externally humans, plants, animals, and microbes but also internally by interrupting their genome and causing mutation and cause permanent change on a species level. It causes many animal and plant species to be endangered. This also interferes with the life cycle of insects and it makes pathogens resistant and cultivars fail to respond better which ultimately leads to food security issues.

Wheat is 90% irrigated by arid and semi-arid climates to grow wheat. Wheat in rainfed areas is most affected by climate change. Climate change affects wheat productivity in Australia, Mexico, every year 2.85 billion dollars of wheat loss [2].

Expected food demand will double by 2050, and production yield losses due to global warming and rise in carbon dioxide concentration. This global warming causes very negative aspects on plants, pathogens, insects, and pests [3].

One of the primary areas of wheat production in both India and the world is the Indo-Gangetic Plain (IGP). Changes in temperature, precipitation, and the amount of water available for irrigation will all have an impact on wheat yields in this area as a result of climate change, posing serious questions about the security of the food supply on a global and national scale. Here, we employ both a crop model and a regional climate model to gain a better understanding of the direct (due to variations in temperature and precipitation) and indirect (due to a reduction in irrigation availability) effects of climate change on wheat yields at four sites located in the Indian Great Plains states of Punjab, Haryana, Uttar Pradesh, and Bihar. The findings indicate that during the growth season, also known as the Rabi season (November–April), there is a rise in the mean temperature, precipitation, and maximum temperature. Depending on the place under investigation, the direct effects of climate change result in losses in wheat production ranging from  $-1\%$  to  $-8\%$  due to variations in temperature and precipitation. Next, the indirect effects of climate change are investigated, taking into account how changes in water supply may result in less irrigation. In this scenario, yield losses escalate significantly, ranging from  $-4\%$  to  $-36\%$ , contingent on the location under investigation and the irrigation schedule used (6, 5, 3 or 1 irrigations). This study demonstrates that for future wheat yields in the IGP, the indirect effects of climate change may be more harmful than the direct ones. It also highlights how complicated climate risk is and how important it is to take into account indirect effects of climate change in order to properly evaluate how it affects agriculture and select the most appropriate adaptation strategy [4].

### **Potential Climate change effect on Sustainability of crop**

Climate change refers to long-term changes in the environment and is one of the major issues of the twenty-first century. A change in the mean or the variable character of the climate's attributes that lasts for a few decades or longer is referred to as climate change. The two basic natural resources needed for plant growth—water and sun energy—are the basis for food production. Climate change therefore has two potential effects on agricultural production. First off, plant growth, development, and yield are directly impacted by variations in temperature, CO<sub>2</sub> levels, rainfall/precipitation, and other factors. Second, a number of variables, including soil organic content, irrigation accessibility, snowmelt, and periodic floods and droughts, may have a big influence on how agricultural land is used. Rainfall determines when to plant and how much water is available. Temperature controls crop

development, but length and relative humidity regulate the occurrence of pests and diseases. Radiation affects the productivity of photosynthetic processes. The physiology of standing crops is significantly impacted by wet and dry spells, which leads to output losses. India's agricultural output would be significantly impacted by each of these events. The influence of climate change on India's sustainable agricultural production is the main topic of this chapter [5].

### **Effect of climate change on wheat growth and production**

Climate change has a very different effect on crop productivity. It is estimated that a 1°C increase in temperature can cause a 10–20% decrease in crop yield globally. Similarly, a 1 to 3 °C increase in temperature is estimated to reduce 20–30% yield reduction in potato crops [6]. This effect can be even worse till the end of this century it is expected to be 2–4°C even more rise in temperature which affects crop production [7]. Change in weather conditions ultimately made extreme climate shift permanently and affect agriculture in the whole world [8]. Heat stress is very critical for future wheat production in Australia, numerous studies are carried out around the globe for risk assessment for yield regarding heat, rainfall, and drought condition along with different cropping patterns [9]. Early maturity rescues the wheat from drought stress in Europe. Drought is linked with low rainfall and high temperature but it can be managed up to some extent [10].

Various studies reported that climate change directly predicts crop yield. Every 1-degree rise in temperature decreases the growth attributes and ultimately the yield. A comprehensive change in growing season temperature was reported. They predict 100 years crop model for global climate change (variation in temperature & rainfall) and their effect on the wheat yield based on 100 years' data [11]. In the north of Europe, flowering time is very much affected by dry climatic conditions and it causes drastic yield losses [12].

Effect of wheat yield with this climate change scenario till 2050 and impact of this change impart negative effect on wheat production. All studies conducted on wheat production were based on global warming and rising temperature with several global climate change models, Hernandez-Ochoa et al. [13] studied the effect of temperature with the rise in carbon dioxide and change in rainfall pattern. The researchers used 5 global climate modeling and 2 ensembles with 2 scaling methods and quantified uncertainty. Spatial and temporal variability at different locations under study showed yield reduction with high temperature and carbon dioxide concentration. The same results were shown with other studies [14].

Under high-temperature spikes, production is reduced and spikes get vulnerable to disease stress. Temperature above 32°C at the time of anthesis, make grain shorter in size, grain filling duration in the spikes is also reduced which ultimately affects the wheat yield [14]. Wheat in rainfed areas is more affected with change in rainfall pattern, rainfall declines and it affects the production of wheat directly, yield decline 5–7 percent with the rise in each degree of temperature [15]. Assenget al. [16] counted in Sudan, and find a 6 percent yield reduction with a 13°C rise in temperature, which was raised from 27°C.

Increased carbon dioxide level is beneficial for C3 plant, as it increases biomass yield and increases metabolism and stomatal conductance as well as an increased rate of photosynthesis. If temperature increases, it changes the uptake of nitrogen, carbon and

decreases the nutritional value of the grains [17]. The condition is even worse when drought, rainfall, and less humidity affect plant growth and production [18].

### **Climate change and diseases attack**

Climate change has a strong impact on the pathogen population. Temperature and water play an important role in the germination and survival of pathogens. In Germany air temperature raised from 0.8–1.1°C from 1900 to 2000, which increase the rainfall during winter, this ultimately suits the pathogen life cycle and helps them for colonization on crop debris and access to particular susceptible hosts [19].

Lucas *et al.* [19] performed an experiment on the survival of three fungal pathogens *F. culmorum*, *F. graminearum*, and *Rhophitulussolani*, decomposed infected leaf of maize with these disease pathogens, and for temperature heating cables were used. Microbial biomass and fungal colonization were observed after 152 days. Pathogen growth was reported with DNA, saprotrophic biomass with glucosamine and for bacteria, muramic acid was measured and values were compared with control. Moreover, it was also observed that *F. culmorum* produces more DNA so it wasn't affected with soil raised temperature but DNA of *R. solani* decreased significantly.

By affecting the geographical and temporal dynamics of disease outbreaks, climate change is projected to have a negative impact on worldwide agricultural productivity. Crop diseases become more severe as a result of physiological changes in plants brought on by rising temperatures and atmospheric carbon dioxide levels. Agro-climatic zone changes brought on by warming may force host plants to move into new regions, which might lead to the formation of new disease complexes. Climate change will have an effect on the global disease scenario because it can influence pathogen development, lead to changes in host-pathogen interactions, and promote the formation of new pathogen races, which in turn undermine host-plant resistance. [20].

In the last 200 years, environmental changes brought on by both natural and human activity have increased globally. In the twenty-first century, it is anticipated that the rise in greenhouse gases will continue to raise the world temperature and alter water availability. Environment has a significant impact on plant illnesses; if the environment is not hospitable to the disease, a vulnerable host won't become infected by a virulent pathogen. Each illness may react differently to changes in CO<sub>2</sub> concentrations, temperature, and water availability, which can have positive, neutral, or adverse impacts on disease development. The idea of illness optima, however, could be applicable to all pathosystems. Environmental influences have an impact on all plant resistance mechanisms, including pattern-triggered immunity and effector-triggered immunity, RNA interference, and defence hormone networks. Temperature and humidity have an impact on the virulence mechanisms of pathogens, including the generation of toxins and virulence proteins, as well as pathogen reproduction and survival. Due to practical considerations, the majority of molecular studies of plant-pathogen interactions in the lab concentrate on well-known pathosystems and employ a limited number of static environmental circumstances that represent just a small portion of the dynamic interactions between plants, pathogens, and their environments found in nature [21].

### **Climate change and insect population**

Climate changes where effect every part of agriculture it does not leave insects unaffected. Plant productivity decreases due to the rise in temperature and drought conditions are directly linked with global warming. When plant population decreases it directly affects the insect population which survives on plants. It also contributed to increasing insect outbreaks [22]. Major insects which threaten wheat yield are wheat stem sawfly, and orange blossom wheat midge, which causes losses up to the economic threshold level [23]. Changes in carbon dioxide amount in the atmosphere have a significant impact on plants, insects, and microorganisms. Insects along with disease pathogens reduce significant yield losses besides all the control strategies [16].

Global warming changes the biochemistry of plants which impacts herbivorous insects and pathogens [24]. Insect populations are disturbed by different abiotic factors due to global warming. Insect population increases in this rising temperature and transmit virus very smoothly from infected to a healthy plant. These climate changes affect badly beneficial insects which cannot survive in dry weather with hot temperatures, it also affects their ability to kill harmful insects. The negative effects of climate change, are an increase in temperature and CO<sub>2</sub> concentration, an increased photosynthesis rate, and increased productivity but reduced agricultural production due to changing weather patterns [25].

Crop output and agricultural pests are significantly impacted by climate change and harsh weather occurrences. Insect pests react to various sources of climate change differently since they are typically adaptive creatures. In this paper, we discuss how changing precipitation patterns, rising temperatures, and atmospheric CO<sub>2</sub> levels affect agricultural insect pests. The most significant environmental factor influencing the dynamics of insect populations is temperature, so it is anticipated that rising global temperatures will cause an increase in their geographic range, overwintering survival, number of generations, risk of invasive insect species and plant diseases, and interactions with natural enemies and host plants. Future pest control techniques are desperately needed as the pest problem gets worse due to climate change. These include keeping track of pest numbers and the climate, modifying integrated pest control plans, and using the modelling prediction tools that are discussed here [26].

The biodiversity of insects has been the subject of several prior studies, some of which have focused on reductions while others have shown changes in species composition without net declines [26, 27, 28, 29,]. Although studies have demonstrated that changes in biodiversity are predominantly caused by land-use change and increasingly by climate change [30, 31] it is yet unknown if these two factors could interact with insect biodiversity on a global scale. Here, we demonstrate how the relationship between historical climate warming indices and intensive agricultural land use is linked to decreases in insect assemblage species counts and abundance of nearly 50% and 27%, respectively, when compared to less disturbed habitats with lower historical climate warming rates. While certain positive responses of biodiversity to climate change occur in non-tropical regions in natural ecosystems, these patterns are more noticeable in the tropical realm. Only in low-intensity agricultural systems does a large supply of adjacent natural habitat frequently offset losses in insect number and richness linked to agricultural land use and significant climate change. Abundance and richness were reduced by 7% and 5%, respectively, in such systems where high levels (75% cover) of natural habitat are present, as opposed to decreases of 63% and 61% in areas where less natural habitat is present (25% cover). Our findings suggest that reducing agricultural

intensity, protecting natural habitat in landscapes, and mitigating climate change will likely all increase insect biodiversity[32].

### **Prediction model for disease elevation in correlation to carbon dioxide**

It was 270 $\mu$ mol/mol which was 408 $\mu$ mol/mol in 2017 [33]. Carbon dioxide is the main constituent of photosynthesis so this affects directly to plant growth and metabolism. But this too much carbon dioxide is harmful to C3 plants, this increases the plant biomass and leads to the carbon dioxide fertilization effect. This phenomenon is explained in different perspectives of the agricultural ecosystem but its extent varied from region to region depending upon the environmental condition and temperature and amount of water in soil [34]. Different regions respond differently to this elevated CO<sub>2</sub> like nutrient uptake, water supply to the plant, water reservoirs in the hot and dry time of year, modeling presents that massive uncertainty in the response of the crop to elevated crop. Wheat is grown everywhere and almost 15% of annual yield is affected by climatic conditions in Mediterranean areas. In Mediterranean regions the main water source is rainfall, which is important for the early growth stages of the wheat plant. The grain filling stage in wheat is badly affected due to a shortage of water supply this condition is termed as terminal drought which ultimately affects the yield of the crop [35]. This drought helps wheat to produce a long root system plus reduce stomatal conductance to conserve available water, but this may be harmful at the grain filling stage. On the other hand, if more water is available then it kept on increasing vigor and plant height, and delayed reproductive stages of the plant may be died off before grain formation. The plant also gets vulnerable to disease attacks [36].

### **Impact of climate change and variability on rice-wheat crops**

Significant drops in crop production have been linked in several Asian regions in recent decades to irregular and severe rainfall patterns, as well as decreased timely availability of water and rainfall [37, 38]. Even with the green revolution's enhanced crop yield, climate change scenarios present significant challenges for maintaining output and enhancing food security for Asia's impoverished rural communities [39, 40]. Damage from climatic shifts may jeopardise national economic production and food security in the least developed nation [41]. Due to differences in climatic trends, yield decreases in various crops (such as wheat and rice) differed among areas [42]. Although it cannot lessen the impacts of rising temperature, CO<sub>2</sub> fertilization can boost crop yield and counteract the dramatic consequences of higher temperatures in C3 plants [43, 44]. Rising temperatures and unpredictable rainfall have a severe impact on crop growth and development [45, 46].

In Asia, rice and wheat play a significant role in ensuring food security. To meet the constantly rising demand for food, it will be extremely difficult to increase wheat production by 60% by 2050 [47]. Reduced crop productivity in arid to semi-arid areas is linked to rising temperatures at lower latitudes. Drought and flooding have decreased the yields of rice, wheat, and maize in China; it is anticipated that these problems will have a greater impact on crop productivity in the future [48]. According to Yang et al. (2017)[49], rice is susceptible to a gradual rise in nighttime temperature. If this temperature increase exceeds the threshold temperature of 24°C by 2°C, rice production and biomass would decrease by 16–52%. Asia's semi-arid to dry regions are in danger of becoming much more so, since poor production and drought stress are already issues. The detrimental effects of rising temperatures and intense, irregular rains have resulted in a decrease in the quality of wheat product (protein content,

sugars, and starch) as well as grain yield [49]. Climate variability has led to a considerable decline in wheat production in the Egyptian North Nile Delta (up to 17.6%), India, and China. This decrease is linked to rising temperatures, irregular rainfall, and an increase in insect pest infestation [50, 51, 40, 52]. According to Chun *et al.* (2016) [53], rice output in rain-fed parts of South Asia has already declined and might do so again by 14% under the RCP 4.5 scenario and 10% under the RCP 8.5 scenario by 2080. Due to their detrimental effects on the booting and anthesis stage, high temperatures and drought have reduced rice yields throughout Asia, particularly in Pakistan and China [54, 55]. Similar to this, heat stress poses a serious risk to rice since it reduces the number of productive tillers, causes grains to shrink, and eventually lowers rice grain output [56]. Rain-fed lowland rice (>13 million hectares) and highland rice (10 m ha) in Asia would be impacted by climate change. Table 1 shows the expected production of wheat and rice crops by 2030.

**Table 1. Shock to productivity brought on by climate change and unpredictability in the production of wheat and rice crops by 2030.**

Countries	Wheat	Rice
China	- 10 to + 14	- 12 to + 12
Philippines	- 10 to + 4	- 10 to + 4
Thailand	- 10 to + 4	- 10 to + 4
Rest of the SE Asia	- 10 to + 4	- 10 to + 4
Bangladesh	- 10 to + 4	- 10 to + 4
India	- 10 to + 4	- 15 to + 4
Pakistan	- 10 to + 4	- 15 to + 4
Rest S Asia	- 10 to + 4	- 15 to + 4

**Source** - Gouldson *et al.* 2016, Assenget *et al.* 2019, Chow *et al.* 2019, Degani *et al.* 2019, Sanz Cobena *et al.* 2019, Suryadi 2020 [57, 48, 58, 60, 61, 62]. Positive (+) sign indicates increase in productivity while minus (-) sign indicates decrease in productivity.

### Management strategies

Global warming affects crop productivity throughout the world. Expensive food items are the first sign of a sudden food shortage in the world's crop yield which will be even more shortly if remain uncontrolled. For this reason, scientist needs to develop crop seeds that are resistant to drought, salinity, and major diseases which are the major threatening factors. So that wheat crop production increases to meet the demand of the human population. Adaptation includes agronomic practices like time of sowing, water management, nutrient availability, timely weeding, and resistant cultivars are helpful tools. Genetically modified crops are important tools for production. It is an easy and quick way as compared to a conventional breeding method which is not reliable and time taking. Molecular breeding enhances the wheat productivity to fight with different abiotic and biotic stresses that crops have to face when cultivated in a field. Molecular markers help to identify the insertion and activity of various genes. Advancement in DNA sequencing helps in finding novel resistant

genes and their insertion in different crops possible [62]. Government should make management strategies for the minimization of global warming. New projects should be designed for the conservation of water loss, minimizing the use of pesticides in fields. Public awareness campaigns should be initiated at the individual level to stop activities that are changing our ecosystem. Pollution-free water should be used to irrigate agricultural land. There should be instruments for the assessment of Carbon concentration in air, and temperature monetization. Training sessions should be made to practice techniques that are helpful in conservation [38].

## Conclusion

Climate changes because an increase in carbon dioxide emission, which causes the greenhouse effect around the globe, it affects all agricultural ecosystems in different ways, sometimes one factor favors plant growth but in combination with other shifts the positive effect into a drastic negative effect. This chapter detail about rise in temperature variation in different regions of the world and its effect on wheat plant growth, biochemistry, grain size and weight, effect on insect pest population, on microbial pathogens. Reviewing literature it has been found that global increase in carbon dioxide helps C3 plants to increase growth, improve plant water uptake capacity and yield of crops. It also favors C3 plants to compete with C4 weed that is grown side by side with the main crop, plants become more resistant to diseases. But these benefits turn negative when the temperature of the area increases, suddenly plants lose the ability to uptake minerals from the soil, and reeducation of grain size, grain weight, and crop resistance towards diseases, increase pest population and water holding capacity of plants. Temperature variation alters the rate of precipitation which ultimately increases drought conditions which is very crucial for wheat growing in rainfed and Mediterranean regions of the world. This condition helps C4 weeds instead of the wheat crop which increases the competition between crop and nutrient for food and water. It is also included as a topic of discussion that if these effects remain uncontrolled it will cause a major food shortage in coming years when food is already expected to be doubled as the world population increases day by day and industrialization increases all these risks. So, it is important to practice the management practices suggested in this chapter to conserve our ecosystem and make this planet a safe place to live.

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