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Chapter

Effect of Climate Change on Wheat Productivity

Ihsan Elahi, Uzair Saeed, Abdul Wadood, Amjad Abbas, Hira Nawaz and Sohail Jabbar

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_2 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 chapter 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_2 curve in 2050.

Keywords: CO_2 elevation, raised temperature, wheat production, prediction model, global warming, metrological advancement

1. 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 effect 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 plants species 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.

Due to global warming agriculture faces serious threats like low crop productivity which leads to global hunger and this low production rise the cost of food commodities and makes it unaffordable for the poor population. Global warming affects the pattern of rainfall which contributes to other disasters. Rise in atmospheric carbon dioxide reduced wheat products as well as nutritional value also down and, in some cases, due to change in the chemical composition some crops start producing toxins [2]. Plant responses to climate change by altering their phenological characteristics. Flowering and fruiting or grain filling in the case of cereals is a very important stage that is particularly affected, it affects pollination, root growth, seed formation, number of seed

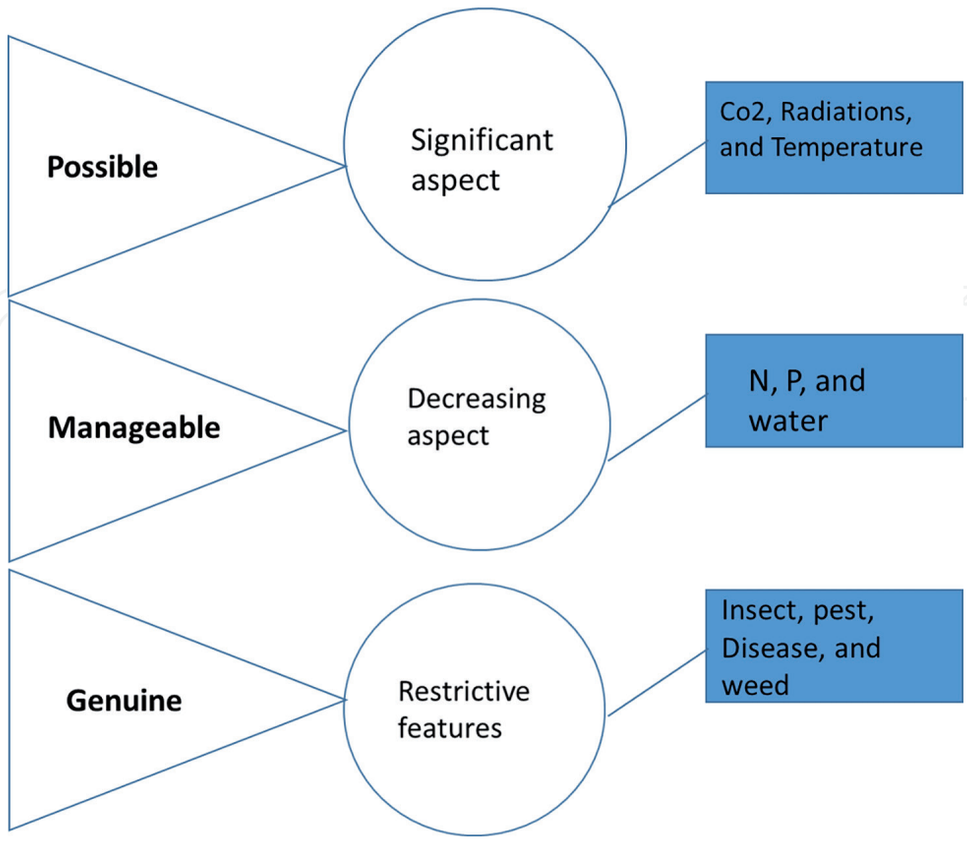

Figure 1.
Crop yield dependency and limiting factors related to climate change [7, 8].

production, leaf expansion, and ripening of the crop. Time for flowering and fruit ripening is affected by the environment, photoperiod, and vernalization [3].

Wheat is a major cereal crop everywhere in the world, it is an important source of energy for the human diet [4]. 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 [5].

Expected food demand will be 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 [6] (**Figure 1**) .

2. Effect of climate change on wheat growth and production

In this hot climate, every prediction regarding climate shows extreme weather conditions [9]. 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 [10]. 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 [11]. Change in weather conditions ultimately made extreme climate shift permanently and affect agriculture in the whole world [12]. These extreme temperature changes during sensitive stages like flowering, anthesis, and milking stage affect wheat yield, grain weight, and grain size at the end of season significantly [13]. Nuttall et al. [14] experimented on wheat production with the combined effect of high temperature and CO_2 enhanced concentration. Results showed that when the temperature was 36 ± 2°C during anthesis it reduced 13 percent and most grains were sterile. Asseng et al. [15] concluded that a 2°C increase in temperature in the Australian core growing area would reduce yield up to 50%. Therefore, 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 [16]. Early maturity rescues the wheat from drought stress in Europe. Drought is linked with low rainfall and high temperature but it is can be managed up to some extent [17].

The wheat crop suffers due to several limiting factors, i.e., biotic (insects, disease, pest, weeds), abiotic stress (heat, cold, drought, and nutrients) effects. At specific wheat growth stages, these factors have decreasing and restricted aspects on wheat crop. The CO_2, radiation, and temperature have positive and significant effects on wheat growth. These factors are directly proportional to the wheat yield [7, 8].

Different studies reported that climate change reported that directly predict crop yield. Every 1-degree rise in temperature decrease the growth attributes and ultimately 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 [18].

In the north of Europe, flowering time is very much affected by dry climatic conditions and it causes drastic yield losses [19].

Wilcox and Makowski [20] used 90 articles and made data set of climate change of different regions, i.e., USA, Spain, UK, and Australia. Variability in average yield is high in regions like UK, USA, and Australia, it ranged between −100 and + 90% in the Australian region.

The conclusion of this analysis includes a meta-analysis for wheat production and yield in the future. Analysis was done with high CO_2 concentration, a decline in rainfall along with rising temperature this increased wheat yield but results varied with location. Meta-analysis for wheat explores quick results regarding wheat production [20].

Effect of wheat yield with this climate change scenario till 2050 and impact of this change impart negative effect on wheat production. All studies carried on wheat production were based on global warming and rising temperature with several global climate change models, Hernandez-Ochoa et al. [21] studied the effect of temperature with the rise in carbon dioxide and change in rainfall pattern. The researcher used 5 global climate modeling and 2 ensembles with 2 scaling methods and quantified uncertainty. Spatial and temporal variability on different locations under study showed yield reduction with high temperature and carbon dioxide concentration. The same results were shown with other studies [22].

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 [22]. 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 [23]. Asseng et al. [24] counted in Sudan, and find a 6 percent yield reduction with a 13°C rise in temperature, which was raised from 27°C.

3. Greenhouse effect and elevation of carbon dioxide on plants

Carbon dioxide in the air is an important source of carbon for plants, unfortunately, this CO_2 level is increasing day by day due to human activities. This elevation not only results in ozone depletion but also affects the growth and yield of field crops. It is observed that an increase in carbon dioxide increases the rate of photosynthesis, it increases water efficiency and high nutrient availability [25]. In C3 plants increase of CO_2 level up to 1 k ppm stimulates the rate of photosynthesis [26] but this does not increase the yield or biomass of the plant. As yield in the wheat crop is depends not only on the rate of photosynthesis but also on the active phase of photosynthesis along with sink capacity of grain [26].

The experiment performed by Fangmeier et al. [27] and concluded that the rise in CO_2 level increases nitrogen sink capacity and also reduces the photosynthetic period which results in poor growth and reduced yield. Another experiment performed by Kimball et al. [28] increase carbon dioxide to 12% with the limited supply of nutrients and yield increase was observed only 7% as compared to control but consume more water. Daepp et al. [29] experimented with wheat by adding nitrogen fertilizer along with elevated CO_2, this nitrogen helps in overcoming carbon sinking especially during the reproductive stage. The researcher concludes that if a crop is grown the plant can be enhanced by using biological nitrogen fixation process, this also favors the yield of legume crops as they already have this natural phenomenon [30].

Carbon dioxide elevation and temperature by a few degrees may disturb the positive aspects. The experiment was done on wheat by doubling CO_2 and increasing 1.5 to 4°C showed a negative effect on wheat yield.

The temperature of the atmosphere is increasing day by day due to global warming and greenhouse gasses. Temperature increases decrease the positive aspects caused by elevated carbon dioxide for plants. The rise in temperature increases the rate of leaf transpiration from the plant [31]. Nevertheless, carbon dioxide elevation can offset the negative effect of high temperature by lowering the stomatal opening and reducing the transpiration rate. Higher temperature can also help in plant production, especially in Mediterranean regions where crop production effects by lower temperature [32]. But elevated CO_2 and temperature change the pattern of rainfall in arid and semi-arid regions which affect plant production very badly. This shift of rainfall has negative as well as positive effects on agriculture. Like in rainfed areas it limits the plant growth while in high rainfall areas it avoids water logging conditions and helps plants to grow well. Wheat is normally grown in the area of less than 550 mm of rainfall and 325 mm is received by the wheat plants in that region. But according to rainfall prediction for 2070, it is expected that by an increase of 10% reduce the winter rain up to 60%, while another research predicted that rainfall will be reduced by 15% till 2030 and 30% till 2070. This prediction is proving right during past years and it is the biggest threat to wheat in rainfed areas of the world [33].

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 [34]. The condition is even worse when drought, rainfall, and less humidity affect plant growth and production [35].

4. Climate change and diseases attack

Fusarium causes different diseases in wheat-like, foot rot, root rot, and head blight in wheat, which causes huge yield losses [36]. *Rhizoctonia solani* is a soil-borne fungus that causes root rot in wheat and causes 50% yield losses in Japan, Europe, and the USA [37]. Climate change has a strong impact on the pathogen population. Temperature and water play 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 [38, 39].

Jacobs et al. [40] experimented on plant decomposition and study on soil temperature and its effect on microbe's survival under natural field conditions. In this experiment amount of bacteria and fungus were counted with the amino sugars and muramic acid. For fungus, ergosterol is used to access fungal biomass as it does not mix with soil organic components plus it is a major part of the fungal cell membrane [41].

Lukas et al. [38] performed an experiment on the survival of three fungal pathogens *F. culmorum, F. graminearum,* and *Rhophitulus solani*, 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.

R. solani germination and infection varied between soil temperatures ranging 15–25°C this were completely disturbed when temperature fluctuate and at 5°C completely stopped [42]. While Fusarium infected the most in raised temperature which shows strong spatial variability [43].

5. 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 directed 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 [44, 45]. This temperature and drought increase causes wildfire and causes plant mortality which ultimately carbon sinks and rising carbon levels in the air [46, 47]. Major insects which threaten wheat yield are wheat stem sawfly, and orange blossom wheat midge, which causes losses up to the economic threshold level [48]. Change in carbon dioxide amount in the atmosphere causes a significant impact on plants, insects, and microorganisms. Insects along with disease pathogens reduce significant yield losses besides all the control strategies [34].

Global warming changes the biochemistry of plants which impacts herbivorous insects and pathogens [49]. 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 [50]. The negative effect of climate change, increase in temperature and CO_2 concentration, an increased photosynthesis rate, and increase productivity but reduce agricultural production due to changing weather patterns [51].

6. Prediction model for disease elevation in correlation to carbon dioxide

The amount of atmospheric carbon dioxide increasing day by day due to the modern standard of living and industrialization. It had been raised to 50% after the industrial revolution [52]. It was 270 μmol/mol which was 408 μmol/mol in 2017 [53]. It was predicted that if carbon dioxide is released at this rate its concentration in the atmosphere will be around 550 μmol/mol till 2050 [54]. 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 [55]. Rainfall in arid, semi-arid, and temperate region and its effect on plants are monitored by free air CO_2 enrichment (FACE) [56]. Different regions respond differently to this elevated CO_2 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 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 [57, 58]. 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 [59].

7. Prediction model temperature elevation

The reason for global warming and temperature variation is CO_2 elevation and many other greenhouse gases which trap heat and raise the temperature in the atmosphere. Prediction on temperature elevation on this planet till 2100 will be increased from 2, 9.7°C which is 1.1–5.4°C is now. The temperature will fluctuate due to heat-trapping gases. CO_2 is added to the air due to the burning of coal and fossil fuels. So, if humans kept on using these things as an energy source, then exact figures for temperature variation are impossible. Scientists work to develop so much for better understanding and awareness in public, they develop a model named as global climate model for prediction, and this is computerized software. This predicts the number of greenhouse gases and concentrations in the air in different situations. For example, the current concentration of CO_2 in the air is 9 billion metric tons per annum and it would be 12 billion if kept on growing till the end of 2040, but if the situation is controlled it can be reversed to 5 billion which was in 1990. Temperature mainly depends upon the carbon dioxide emission if it increases temperature will go up and vice versa [60, 61].

8. 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 [63].

9. Conclusion

Climate changes cause an increase in carbon dioxide emission, which causes the greenhouse effect around the globe, it affects all agriculture 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 practice suggested in the chapter to conserve our ecosystem and make this planet a safe place to live.

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