

Physiological Response of Plants to Climate Change Importance and Mitigation Strategies: A Review

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ABSTRACT

Climate change is a global problem affecting millions of people worldwide. Climate change has a significant impact on plant physiology and growth. Plants are exposed to a wide range of environmental and biochemical stresses, such as ozone (O₃), nitrate (NO), phosphorus (P), nitrogen (N), and sulphur (S) during reproductive and grain-filling phases. Atmospheric CO₂ concentrations predicted for 20 Celsius of global warming will have major implications for plant growth and performance. Climate change has increased global concern about crop yield and food security. According to climate change forecasts, a steady increase in average atmospheric temperature or the occurrence of frequent environmental extremes will have a severe influence on physiological and biochemical functioning. As a result, understanding plant tolerance mechanisms has aroused the interest and concern of academics working on crop resilience toward climate-smart agriculture and thus food security in the face of climate change. Indeed, plants can reduce stress injuries or damages by employing diverse methods such as avoidance or utilising multiple intrinsic resistance mechanisms. In fact, plants can reduce stress injuries or damages by employing diverse methods such as avoidance or utilising multiple intrinsic resistance mechanisms. This review paper focuses on how plants will respond to high CO₂ that are close to the temperature hazards that exist in the real world. It also discusses how plant structures and processes (like photosynthesis and transpiration) will adapt to climate change. Plant adaptations or tolerance mechanisms to environmental extremes have also been discussed. This relevant information is crucial for agricultural sustainability and food security because enhanced understanding can help improve plant resilience to climate change through the use of contemporary breeding procedures and biotechnological or genetic engineering tools.

Keywords: Climate change, Photosynthesis, drought stress, elevated temperature

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INTRODUCTION

Cause of Climate Change

Natural Causes

There are number of biological and natural causes for emerging of climate change. Some of the important factor are volcanoes, ocean currents, continental drift.

- **Volcano-** When a volcano erupts, it spews large amounts of sulfur dioxide (SO₂), water vapor, dust, and ash into the atmosphere. Although volcanic activity may only last a few days, large volumes of gases and ash can affect climate patterns for years. Gases and dust particles partially block incoming sunlight, resulting in cooling.
- **Ocean current-** Oceans are a major part of the climate system. They cover about 71% of the Earth. The oceans absorb about twice as much solar radiation as the atmosphere.
- **Continental drift-** The continents were formed when the land began to drift apart millions of years ago. This drift changed the position of the land's water bodies and the flow of ocean currents and winds. These changes affect the climate. This continental drift continues to this day.

Anthropogenic Causes

Causes that are created by humans are called Anthropogenic factors. Producing electricity and heat by burning of fossil fuel causes a large portion of global emissions. It produce large amount of CO₂ and NO which is powerful greenhouse gases that cover the Earth and trap the sun's heat. Cutting down forest tree for farming and pasture causes emission, since tree store most of the carbon. Each year approximately 12 million hectare of forest are destroyed. Destroying them also limit the carbon storing capabilities. Transportation is major contributor of green house gases. Industrial processes also release artificial and new greenhouse gases like CFCs (chlorofluorocarbons), while automobile exhaust fumes lead to ozone generation. The resulting enhanced greenhouse effect is more commonly referred to as global warming or climate change. Road vehicles account for the

largest part, due to the combustion of petroleum-based products, like gasoline, in internal combustion engines. Producing food causes mainly methane and any other gases in various ways.

Climate change and Crop production

Plant physiology has been greatly affected by climate variability in several ways. Environmental extremes and climate variability have increased the likelihood of numerous stresses on plants. (Thornton et al., 2014) Climate change is a long-term challenge, but given the pace and scale at which greenhouse gases are accumulating in the atmosphere and the risk of a global temperature increase of more than 2°C, urgent action is required. Greenhouse gases (CO₂, O₃ and CH₄) impact on climate change it directly affect crop productivity (IPCC, 2014). A higher concentration of CO₂ is expected to act as a fertilizer by improving net photosynthetic rates and increasing water use efficiency (Long et al., 2004; & Deryng et al., 2016). The productive impact is greater in C₃ plants such as rice, wheat and soybean because of restricted photosynthetic output of photo respiratory carbon losses. However, in the long term, the continued increase in CO₂ concentration will have a negative impact on the climate, balancing out the increase in crop yields. (Specht et al., 1999; Long et al., 2004; Dong et al., 2018; Senapati et al., 2019; & Wei et al., 2019) besides, ozone (O₃) changes have significant negative impact on the yield of major agricultural crops. O₃ is one of the most reactive oxidants that causes damage to plant tissues, including visible leaf damage, reduced photosynthesis, and accelerated senescence and cell death (Vandermeiren et al., 2009). But interestingly, there are marked differences in O₃ sensitivity between species (Mills et al., 2007). O₃ causes a decrease in crop biomass in wheat and soybean, more specifically in root biomass, during the reproductive and grain-filling phases, leading to a decrease in overall crop yield. Consequently, global production losses due to O₃ in these crops are expected to be higher than those in rice and maize (Van

Dingenen et al., 2009; Avnery et al., 2011; Tang et al., 2013; Feng et al., 2019; & Wang et al., 2019).

Effect of Elevated CO₂ on Photosynthesis and Carbon Partitioning

Since the Industrial Revolution, global atmospheric CO₂ concentrations have increased rapidly, rising from 280 ppm to the current over 400 ppm (Tans & Keeling, 2016). Prediction warn that global CO₂ concentrations will continue to rise, in rise due to continued human carbon emissions (Meehl et al., 2007). As photosynthetic organisms, plants take in atmospheric CO₂ and chemically reduce carbon. This represents not only the retrieval of stored chemical energy for the plant, but also provides the carbon skeletons for the organic molecules that make up the plant's structure. Overall, the carbon, hydrogen, and oxygen assimilated into organic molecules by photosynthesis make up ~96% of the total dry matter of a typical plant (Marschner, 1995).

Photosynthesis is a crucial process for controlling variables of crop growth and exposing C₃ plants to eCO₂ generally increases photosynthesis (Drake et al., 1997; Ainsworth & Long, 2005; & Wang et al., 2012). Increase in photosynthesis under eCO₂ mainly happen due to increase in RuBP which is ribulose-1,5-bisphosphatemcarboxylase/oxygenase (Rubisco) activity. Rubisco catalyzes the carboxylation of RuBP, which is required for CO₂ fixation, but also uses O₂ as a substrate to oxygenate RuBP in a process called photorespiration (Makino and Mae, 1999). The carboxylation reaction of RuBP is not saturated at the current atmospheric CO₂, therefore, as the availability of CO₂ increases under CO₂ conditions so too will the rate of carboxylation (Drake et al., 1997). Photorespiration is another wasteful energy process, because it costs the plant more energy and results in no energy or carbon gain (Peterhansel et al., 2010). Biomass increases in rice and winter wheat under eCO₂ concentrations have been widely reported (Dijkstra et al., 1999, Kim et al., 2003, & Yang et al., 2006).

Carbon dioxide concentrations are also essential for regulating the openness of stomata, the pores through which plants exchange gases with the outside environment. The open stomata allow CO₂ to diffuse into the leaves for photosynthesis, but also provide a pathway for water to diffuse out of the leaves. Plants therefore regulate the degree of stomatal opening (which also known as stomatal conductance) as a trade-off between maintaining a high rate of photosynthesis and a low rate of water loss. As the concentration of CO₂ increases, plants can maintain a high rate of photosynthesis with a relatively low stomatal conductance. In various FACE (free air carbon dioxide enrichment) experiments, growth under elevated CO₂ reduces stomatal water conductance by an average of 22% (Ainsworth & Rogers, 2007).

Increased level of CO₂ give rise to many chemical present in plant tissue. Under FACE experiment increased photosynthetic activity, leaf nonstructural carbohydrates (sugars and starches) per unit leaf area was found increase on average by 30–40% (Ainsworth, 2008; Ainsworth & Long, 2005). Also nitrogen status in plants give idea about protein concentration in plant tissue. Changes in plant tissue nitrogen are therefore likely to have main effects on species at higher trophic levels. Performance is usually reduced in insect herbivores that feed on plants grown in elevated CO₂ (Zvereva & Kozlov, 2006). This can lead to increased consumption of plant tissues as herbivores compensate for reduced food quality (Stiling & Cornelissen, 2007).

Effect of Elevated CO₂ on C₃ and C₄ plants

One of the most important determinants of species differences in response to elevated CO₂ is photosynthetic type. Most plant species (~90%) use a photosynthetic process known as C₃ photosynthesis. Other species use one of two physiologically distinct processes known as C₄ and CAM photosynthesis. C₄ plants include most tropical and subtropical grasses and several important crops, such as maize, sugarcane, sorghum, and millet.

An increase in CO₂ has been suggested to increase the water use efficiency (WUE) of C₃ species by causing a decrease in the rate of transpiration and an increase in the rate of CO₂ assimilation by plants. In C₄ species, the positive effect of increased [CO₂] on

photosynthesis can be apparent under drought conditions (Seneweera et al., 1998; & Leakey, 2009). However, elevated CO₂ also increased the growth of several C₄ grasses even under water saturated condition.

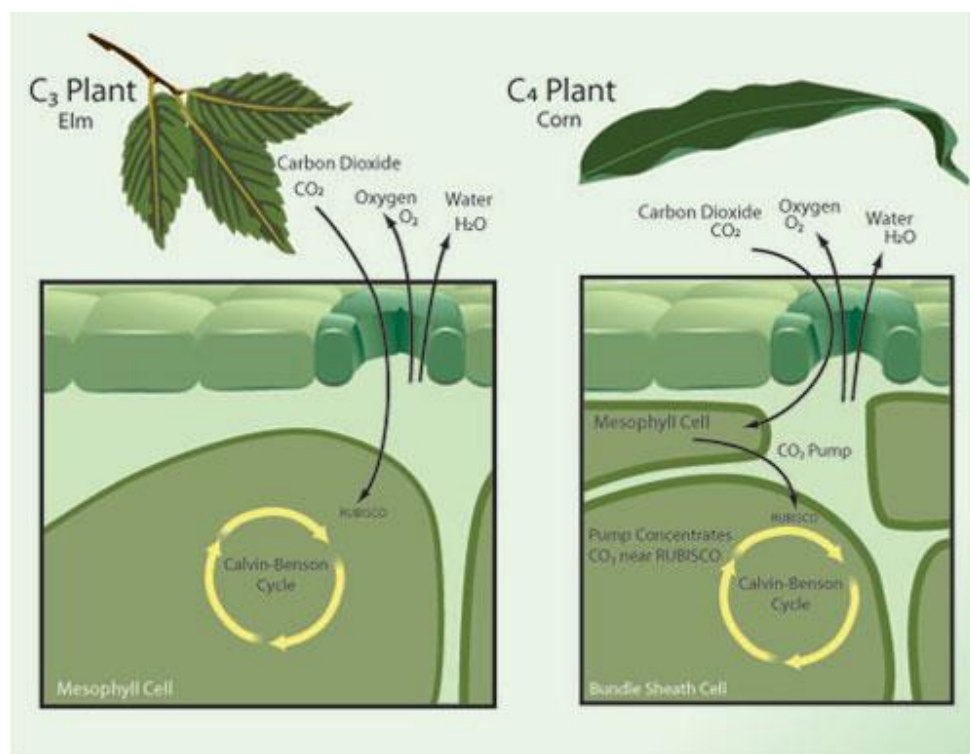


Figure1. Each plant species utilizes one of several distinct physiological variants of photosynthesis mechanisms, including the variants known as C3 and C4 photosynthesis.

Source: Taub, D. (2010)

Effect of Elevated Ozone level on physiology and growth

Topospheric ozone (O₃) is one of the most deleterious air pollutants which is generated by complex photochemical reaction from its precursors, such as NO, CO and volatile organic compounds. Many crop plants such as wheat (Li et al., 2018), rice (Feng et al., 2018), soybean (Morgan et al., 2003) and maize (Mills et al., 2018) are sensitive to O₃ and their production is greatly influenced by O₃ Pollution.

In vegetable crops, O₃ has been reported to increase both enzymatic activity associated with general plant defense mechanisms and antioxidant concentration (Caregnato et al., 2013; & Kumari et al., 2015).

It has been shown that elevated O₃ not only induces visible tissue damage, inhibits photosynthesis, reduces plant biomass and crop yields, but also alters below ground C allocation and the composition and diversity of soil microbial communities (Calatayud et al., 2004; Wang et al., 2007, 2015; Chen et al., 2008; Zhang et al., 2012; & Feng et al., 2014). Plant responses to O₃ are complex and specific. Increased O₃ could increase both enzymatic activity associated with general plant defense mechanisms and antioxidant concentration (Caregnato et al., 2013; & Kumari et al., 2015).

O₃ stress also changed the balance of structural and non-structural carbohydrates, which is one of the most intriguing

biochemical responses of plants. (Darrall, 1989; & Chen et al., 2015) Carbohydrate metabolism create link between carbon dioxide (CO₂) fixation and biomass production. Therefore, some experiment show changes in carbohydrate pools (Neufeld et al., 2012), carbohydrate metabolism (Sild et al., 2002) or allocation (Chen et al., 2014a) in response to elevated O₃.

Effect of elevated temperature on plant and their membrane

The global mean temperature projected to increase by 1.4 to over 5°C by 2100 (Houghton et al., 2001; & McCarthy et al., 2001). Plants may suffer from the ups and down of temperature of their exterior environment. Although, global warming affect plants more than animals, they often regulate their own temperature. Plants experience substantial damage from high temperature stress. Crop yield decrease by 17% for each degree Celsius increase in average season temperature. (Lobell & Asner, 2003).

Temperature greater than 40°C affects many crops by generate thermal damage, inhibition of photosynthesis and change in protein structure and functions such as protein unfolding, denaturation, aggregation, and enzyme inactivation reaction. Photosystem II is highly affected by temperature and it decrease its function. High temperature affects PSII in many ways such as dissociation of antenna complex from the core complexes, inactivation and dissociation on oxygen evolving PSII complexes. (Busheva et al, 2012; & Hu et al, 2018). The photosynthesis and carbon fixation are disrupted by temperature, chlorophyll also degrade which result in leaf senescence. (Jejic et al., 2015; & Ferguson et al., 2020)

Cellular membrane and cell compartment disrupt due to high temperature it leads to solute leakage and affect cellular function. It causes physiological injuries and leaf senescence. Cell membrane disruption related to increase in membrane lipid peroxidation, which occurs when double bonds of unsaturated fatty acid is attacked by

Reactive oxygen species (ROS). (Smirnof et al., 1993; & Foyer et al., 1994).

Lipid membrane fluidity is important for membrane function, which depends on interactions between lipid and protein compositions. Increasing membrane fluidity results from HT-induced higher degree of lipid unsaturation (Fan et al., 2015; & Liu et al., 2017). So reduce membrane fluidity under high temperature, lipid unsaturation could be reduced by down regulation fatty acid desaturase (FAD) gene (Holthius et al., 2014). Maintaining optimal composition unsaturated fatty acids are important in determining the fluidity of the cell membrane under high temperature. In heat tolerant plants below high temperature, the degree of saturated fatty acids increases both in thylakoid membranes (Vigh et al., 1989) and in cell membranes. A heat tolerant wheat genotype showed higher amount of unsaturated fatty acid specially linolenic acid (18:3) to maintain membrane fluidity. (Narayanan et al., 2016). It has also seen that elevated temperature reduce spikelet fertility in Rice by inhibit anther dehiscence and decrease pollination (Wang et al., 2019).

Effect of drought stress on plant metabolism

Water scarcity is a severe environmental constraint to plant productivity. Drought termed as prolonged shortage of water supply due to below average rainfall in a given area. Drought stress affect the many physiological and biochemical changes in plants which ultimately reduced the total biomass production. Almost the 80-95% of water comprised in plant fresh biomass, which play a vital role in many growth, development and metabolism (Broderson et al., 2019) Water loss due to global warming does not only occur in the soil, but also at the plant level. The internal water in plants is being largely lost to the atmosphere due to increased temperatures due to global warming, a phenomenon that further exacerbates preexisting water scarcity problems in various agricultural systems around the world.

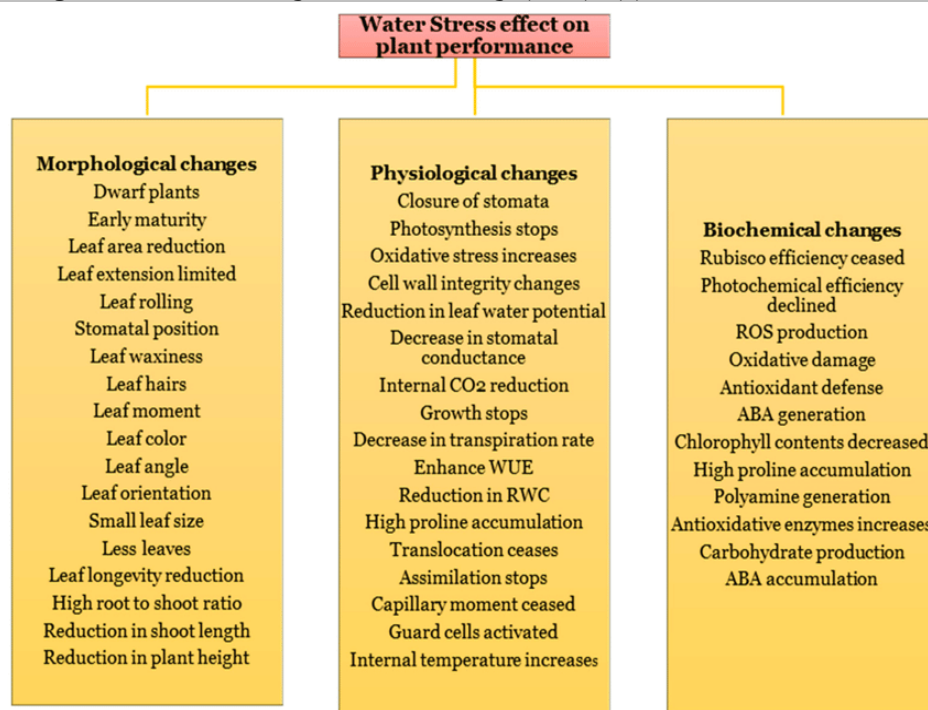


Figure 2 Morphological, physiological and biochemical dynamics of plants affected by water stress.

Source: Seleiman, M.F (2021)

Water deficit outbreaks are caused by the occurrence of less or no precipitation, resulting in low soil moisture content and low water potential in the aerial parts of the plant, such as leaves and stems (Ristvey et al., 2019). When this happens, the rate of water loss through transpiration from the leaves will exceed the rate of water uptake by the roots in a dry environment. (Goche et al., 2020) Roots try to absorb more water through their expansion and this ultimately adapts plants to minimize stomatal water loss when water is scarce (Martínez et al., 2017). Typical symptoms of drought stress in plants include leaf rolling, plant stunting, leaf yellowing, leaf burn, permanent wilting (Corso et al., 2020). Moreover, the response of plants to a given water deficit is strongly dependent on the previous occurrence and intensity of other drought stress events (Adnan et al., 2020) and the presence of other stresses.

Instead of the adverse effects that water deficit has on plant performance, plants have the potential to respond to varying degrees of water deficit. There is a strong correlation between plant growth and water availability, as cell enlargement is more affected by water deficit than cell division

(Humplík et al., 2017). Under these conditions, plant growth is inhibited due to a reduction in cell wall extensibility and turgor (Seleiman et al., 2019). When drought conditions are severe, respiration may also decrease, although an increase in respiration has been observed under mild stress (Birami et al., 2018). To cope with water deficit, osmotic adaptation of stressed plants is maintained by increasing sugar content in roots and leaves, and relatively greater root growth compared to shoots has been observed in drought-stressed plants in the past (Miranda et al., 2020).

Associated effects of climate change factors on development

Plants will not face climate change factors individually, but will be experience multiple factors of environmental changes in the future. However, most studies of plant developmental responses to climate change expose plants to only one climate change factor at a time. While exposing plants to a single driver of climate change is experimentally manageable, it also limits our ability to draw conclusions about plant responses to realistic climate change scenarios. Studies that have been conducted on interactive climate change factors have often shown interactions that

differ significantly from the effects of climate change factors applied independently.

Soybean crop has shown the predicted stimulation of seed yield by elevated CO₂ diminishes as drought stress increases (Bishop et al., 2014). C₄ crop maize, elevated CO₂ did not significantly affect shoot biomass or seed yield, but elevated temperature reduced seed yield in both ambient and elevated CO₂ (Ruiz-Vera et al., 2015).

It has been also found that increment of leaf area by elevated CO₂ is reduced when plants are introduced to drought in combination with elevated CO₂ by many species, include sweet gum (*Liquidambar styraciflua*) and sugar maple (*Acer saccharum Marsh.*) (Tschaplinski et al., 1995) These studies suggest that drought conditions likely to co-occur with increased CO₂ in the future will alter previously observed plant growth and developmental responses to increased CO₂ alone. In addition, the molecular mechanisms of plant response to these combined treatments are unknown.

CONCLUSION

Atmospheric CO₂ concentrations predicted for 2100 will have major implications for plant physiology and growth. With increased CO₂, most plant species show higher photosynthetic rates, increased growth, reduced water consumption, and reduced nitrogen and protein tissue concentrations. Elevated CO₂ also have positive effect under drought condition because it increases osmotic adjustment. When eCO₂ levels are high or low, rice and winter wheat respond differently in terms of photosynthesis and growth. The photosynthetic efficiency and development of plants, particularly for C₃ plants, are often less sensitive to low eCO₂ concentrations because they are closer to the normal growing environment of plants. Understanding how plant structures and processes (like photosynthesis and transpiration) will adapt to climate change is crucial. The first step in ensuring that plants are better prepared to handle future climate change is to improve hydraulic efficiency. To better understand the

mechanisms underlying plant tolerance to diverse stresses, it is crucial to examine how plants respond to high CO₂ levels that are close to the temperate hazards that exist in the real world. Establishing a role for a hormone in protecting crop production from abiotic stress may have substantial consequences in breeding programmes as well as field use of plant hormones because phytohormones are essential in conferring tolerance.

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Conflict of Interest:

There is no such evidence of conflict of interest.

Author Contribution

Both author have participated in critically revising of the entire manuscript and approval of the final manuscript.

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