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Global Climate Change and Crop Production

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Abstract

Uncontrolled emissions of greenhouse gases and other air pollutants due to industrialisation and land use change are causing global warming and climate change. Elevated CO_2 triggers global warming by absorbing infrared radiation and warming the Earth's atmosphere. Increased CO_2 and higher temperatures interact with C_3 and C_4 plants and affect plant growth and productivity through changes in various physiological and biochemical processes. Photosynthesis is affected by various physiological mechanism such as photorespiration, stomatal conductance, water use efficiency, transpiration and phenological processes. Therefore, it is expected that reduced crop quality and productivity would be a challenge in terms of food security for future generations. For this reason, it is necessary to develop adaptation strategies to ensure sustainable agricultural production. Thus, improving plants adaptation ability to environmental and geographical conditions is now an important issue to preclude reduced crop quality and yield loss. This reviews examines the physiological effects of global climate change on plants and determines the measures that can be taken for this situation.

Keywords: Global warming, C_3 and C_4 plants, crop productivity

INTRODUCTION

Regardless of socioeconomic conditions, food security is the access to sustainable, sufficient and balanced food. Meeting nutritional needs is vital for an active and healthy life. Adequate food produced globally must be accessible to people in the right quantity and quality (Capone et al., 2014). Since one of the most important principles of the food supply is continuity, stability and sufficiency in agricultural production are important (Lu et al., 2022). However, environmental impacts within the scope of global climate change stress cause some effects on agriculture (Sangeetha et al., 2022) and global food production.

Climate change can be defined as the long term shift in global and local weather patterns primarily caused by anthropogenic activities (Anonim, 2023). Natural events and human activities on Earth affect climate change. These natural events include fluctuations in solar energy, changes in the earth's orbit and terrestrial reflection, and volcanic eruptions. (Nwankwoala, 2015). The effect of human activities has mostly been on greenhouse gases emissions. The emission of greenhouse gases (Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and hexafluoride) which started in the beginning of the industrial revolution and continues until today, has significantly affected the global climate change process (Wuebbles and Jain, 2001; Peter, 2018). Greenhouse gases keep the earth's temperature at 15 °C, making life possible for living beings. Greenhouse gases in the troposphere absorb the long-wave radiation reflected from the earth's surface and retain it as heat. Otherwise, the earth's temperature would be -19 °C and life on Earth would not be possible (Kweku et al., 2018). The increase in the concentrations of greenhouse gases (such as carbon dioxide, methane, nitrous oxide, ozone, and chlorofluorocarbons) prevents the reflection of long wavelength rays back into the atmosphere. On the other hand, long-wavelength rays absorbed by greenhouse gases transform into heat energy, causing warming on the earth and changes in other climate elements (Al-Ghussain, 2019).

Climate change is changing at an ever-increasing rate due to global warming. Carbon dioxide is the most important anthropogenic greenhouse gas affecting climate change (Montzka et al., 2011). The carbon dioxide concentration, which was 280 ppm (Luthi et al., 2008) before the industrial revolution, has increased to 417 ppm with an increase of 49% since 1950 (Steffen et al., 2007). It is predicted that the carbon dioxide concentration in the atmosphere will be 541 ppm by 2050 (Beach et al., 2019). The increase in carbon dioxide concentration also affects other climate elements. It is expected that the Earth's temperature will increase due to the increase in carbon dioxide and other gases that absorb infrared rays in the Earth's atmosphere (Petrov, 2022). The climate models are examined, 1°C temperature increase is expected for every 100 ppm carbon dioxide concentration increase (IPPC, 2022). Some researchers also support this statement and state that the air temperature will increase by about 2 degrees until 2050 (Dreyfus et al., 2022; Mathew, 2022). This increase in temperature affects the amount and distribution of precipitation, causing extreme droughts in various parts of the planet, and increases in global temperatures will cause more evaporation, different parts of the planet that are not currently affected by drought will likely be adversely affected by water scarcity and limit the amount of arable land as well as food production (Martínez-Goñi et al., 2022). Changes in climatic events such as temperature, precipitation amount and distribution (Dumont et al., 2015) affect the growth rate, photosynthesis efficiency, transpiration rate, water use efficiency, and thus the yield and quality of plants. It is predicted that the resulting change will affect crop production as well as agricultural inputs such as agricultural irrigation, pesticides, fertilizers, and environmental issues such as drainage density and erosion (Saglam et al., 2008; Yavas and Unay, 2018).

TÜRKİYE'S AGRICULTURAL PRODUCTION POTENTIAL

When the agricultural production potential of Türkeye is examined, it is seen that 54,9% of the production is made up of cereals. Wheat (28%) has the highest share in production, followed by barley (12,1%) and grain corn (12,1%). Rice ranks third with 1,3%. Another plant with a significant contribution in Türkiye is sugar beet, which accounts for 27,3% of the production. While dried legumes (broad beans, peas, chickpeas, dry beans, red lentils, green lentils, kidney beans, wild vetches, fenugreek, grass pea) constitute 1,9% of the production, oilseeds (soybeans, groundnuts, sunflower, sesame, safflower, rapeseed, flax (seed), hemp (seed), poppy (seed) make up 4,4%. (TUIK, 2023). When we look at the rangelands vegetation of Türkiye apart from production, it is seen that C_3 grasses are dense in the vegetation of areas with steppe climates (Erkovan et al., 2008). The meaning of this is that the vegetation cover and the majority of the plants produced in our country as well as in the world consist of C_3 plants. It is known that the effects of global climate change on C_3 and C_4 plants are different.

CROP RESPONSE TO CLIMATE CHANGE

Increasing atmospheric CO_2 and changing climate elements due to this increase will affect the growth period, development, yield and quality of plants positively or negatively. This effect will vary depending on the plant type, for example, C_3 and C_4 (Poorter and Perez-Soba, 2001; Leakey, 2009; Uddling et al., 2018). Different types of plants will also have different responses to global climate change due to some physiological characteristics such as the pathway used to reduce carbon dioxide, photorespiration, and stomatal conductivity. These physiological changes caused changes in the plant's morphological characteristics such as leaf size, shoot-root ratio, and grain size (Masle, 2000; Seneweera, 2011). C_4 plants have higher water, nitrogen and light utilization efficiency compared to C_3 strains due to their anatomical, physiological and genetic adaptations. Approximately 8100 of the approximately 250 thousand plant species in the world are C_4 species and although they are taxonomic in small numbers, the annual primary productivity is high. It makes up 25%. A large part of current agricultural activities are carried out with C_3 species. Three major C_4 crops account for about 15% of the annual world agricultural production (Ceylan, 2019). This review will investigate the physiological responses of C_3 and C_4 plants to changing climatic conditions and how this will affect yield and quality. In addition, plant breeding strategies that should be focused on plant breeding will be mentioned.

The Response of Plants to Changes in CO_2 in the Atmosphere

Significant changes in atmospheric CO_2 have occurred in the geological past and in the 21st century. It is reported that before 1800, the CO_2 in the atmosphere varied between 180-290 ppm for at least 220 years, and there were significant increases from 315 ppm to 360 ppm until 1990 (Hall and Allen, 1993). It is stated that the concentration of CO_2 in the atmosphere in the 20th century was 380 ppm (Boisvenue and Running, 2006). At the end of the 21st century, it is estimated that the CO_2 concentration in the atmosphere will have a value between 600-1000 ppm (Xiao et al., 2009).

Many species follow the C_3 pathway, where CO_2 is first fixed by Ribulose-1,5-bisphosphate (RuBP) and catalyzed by Ribulose-1,5-bisphosphate carboxylase/oxygenase (Rubisco) (Sage et al., 1989). This carboxylation reaction produces 3-PGA (3-phosphoglycerate) molecules, a stable three-carbon compound hence it is called C_3 plant. But Rubisco also has oxygenase activity by fixing O_2. In C_3 plants, when the O_2 concentration is higher than the CO_2 concentration, photorespiration occurs only in light. 20-30% of the CO_2 fixed by photosynthesis with photorespiration is lost with this physiological event (Sonmez et al., 2022). Some plant species use the C_4 pathway, where CO_2 reacts first, and fixation with phosphoenolpyruvate (PEP) forms the compound malate or aspartate. It is a four carbon stable molecule and therefore it is called the C_4 plant. This enzyme (PEP) is not bifunctional and binds only CO_2.

It is stated that photosynthetic activity increases at high CO_2 concentrations and accordingly, growth increases in most plants depending on the plant species. The increase in plant growth is reported to be 10-15% in C_4 plants and 33-40% in C_3 plants (Kimball, 1983). The fact that this rate is higher in C_3 plants, at CO_2 concentrations higher than 600-1000 ppm on average, the uptake of CO_2 by stomata is facilitated and carboxylation is provided by decreasing the oxygenation time in the Rubisco enzyme. Therefore, photorespiration is prevented. Thus, the yield of C_3 plants increases more. Photosynthesis in C_4 plants is somewhat saturated at the current CO_2 concentration. In C_4 plants, 4-carbon compounds synthesised in mesophyll cells are the source of CO_2 in bundle sheath cells. Therefore, the photosynthesis rate of C_4 plants is high even under low CO_2 conditions (Yavas ve Unay, 2018). Consequently, C_4 species are not expected to be affected by increasing CO_2 concentration. Theoretically, the ratio of net assimilated CO_2 to unit leaf nitrogen content has been defined as "photosynthetic nitrogen use efficiency" (Leakey et al., 2009) and the ratio of leaf carbon gain in net photosynthesis to water loss by transpiration per unit leaf has been defined as "photosynthetic water use efficiency" (Way et al., 2014). It has been determined that C_4 plants utilise water and nitrogen more efficiently than C_3 plants under conditions of increased CO_2 (Sage and Percy, 1987; Leakey et al., 2009).

High CO_2 affects the yield as well as quality of many plants (Saxena and Naik, 2018). High CO_2 concentration causes changes in various physiological and metabolic processes that begin to differentiate in biochemical compounds such as carbohydrates, proteins, fatty acids, secondary metabolites, vitamins, as well as a decrease or increase in macro and micronutrients according to different organs of the plant (Wang and Frei, 2011).

Responses of Plants to Temperature Increases

One of the issues to take measures against global warming is the increase in temperature. Temperatures above optimum (24-25 °C for winter cereals and 34-36 °C for summer crops) rapidly reduce net CO_2 assimilation. Climate modelling studies indicate that winter temperatures will increase by 5 °C and summer temperatures by 3 °C by 2060 (Reddy and Hodges, 2000). The productivity of many plant species is particularly sensitive to high temperatures, especially high night temperatures, such that fruit or seed yields are reduced more than total biomass production at high temperatures (Hall and Allen, 1993).

Temperature increases can cause changes in the phenological characteristics of plants through deviations in vernalisation, photoperiodism, hormonal changes and their interactive effects (Sparks et al., 2000). High temperatures are highly effective on gene function and enzyme reaction in plants. In other words, high temperatures in the vegetative period do not have much negative effect on plant growth and development. However, it has a destructive effect during the generative period (from beginning of florsl initiation to seed developmenty). Temperature increases adversely affect the flowering period in many plant groups, reducing the grain retention rate and reducing the transport of photosynthetic products to the grain, causing large losses in yield (Yang et al., 2017; Prasad et al., 2019). On the other hand, increasing night temperatures negatively affect generative organ formation by increasing respiration.

Physiological processes such as photosynthesis and respiration related to growth in plants react negatively after a certain temperature (Basaran and Akcin, 2022). When the temperature rises above the optimum, the carbon binding efficiency of the Rubisco enzyme in C_3 plants decreases, photorespiration increases, and thus net photosynthesis decreases (Sharwood et al., 2016).

Effects of High Temperature and High CO_2 Interactions on Plants

The interactive effects of high CO_2 concentrations and high temperatures on plants are complex (Conroy et al., 1992). However, they can be simplified if the situations in which temperature stress limits processing and storage during the reproductive period are distinguished from those in which it limits the photosynthetic resource. In many cases reproductive development is more sensitive to high temperatures than total biomass production. Many studies have shown that the detrimental effects of high temperature on reproductive development are not alleviated by high CO_2 concentration (Hall and Ziska, 2000). Where the photosynthetic resource is particularly sensitive to temperature stress, the interactive effects of elevated CO_2 are less pronounced.

Plant Water Relations and Global Climate Change

Another issue affected by temperature increase is water utilisation efficiency. The increase in evaporation with increasing warming causes a decrease in available water (Karaman and Gökalp, 2010). With water deficiency, stomatal constriction occurs and CO_2 uptake decreases (Ors and Ekinci, 2015). In case of low air humidity (ideal air humidity is 65-85% humidity in the plant canopy) and insufficient soil moisture, the decrease in CO_2 uptake is more severe.

Plant growth depends on the supply of water lost in the process of transpiration and carbon assimilation. There are many different perspectives on water use efficiency. At the leaf or plant level, water use efficiency is calculated based on the amount of CO_2 bound and the amount of water lost through evaporation and transpiration from the soil surface. For an agronomist, however, water use efficiency refers to the total yield of water quantity supplied during the growing season.

Water scarcity is the most important environmental constraint that inhibits plant growth. In water scarcity stress, plants first try to prevent water loss by closing their stomata. However, preventing water loss from leaves also means preventing gas exchange and this leads to a decrease in photosynthetic capacity (Uzilday et al., 2014). Since CO_2 diffusion decreases in plants using C_3 photosynthesis, photosynthesis increases and the assimilation capacity of the plant decreases (Bauwe et al., 2010). C_4 plants fix CO_2 in mesophyll cells with the help of phosphoenolpyruvate carboxylase (PEPC) and then this CO_2 is released into the bundle sheath cells. Ribulose1,5-bisphosphate carboxylase/oxigenase (Rubisco) tightly fixes CO_2 in these cells. By this mechanism, the availability of CO_2 around Rubisco is increased and the rate of photosynthesis is minimised (Gowik and Westhoff, 2011). Since they can concentrate CO_2, C_4 plants tend to have lower stomatal aperture than C_3 plants. Thus, C_4 plants increase their water use efficiency (Way, 2012).

Possible factors that increase photorespiration are heat, drought, high light and salinity (Moore, 1983; Sage, 2001; Osborne and Freckleton, 2009; Edwards and Smith, 2010). In particular, drought induces photorespiration by reducing stomatal conductance, which reduces intercellular CO_2 levels, and also by affecting Rubisco kinetics (Sage, 2013). This suggests that among plants under abiotic stress-inducing photorespiration, C_4 plants may be more robust than C_3.

Plant Pest Contracts and Global Climate Change

CO_2 limited experimental evidence of direct effects on insects available, while more concrete results on increasing temperature are available (Caulfield and Bunce, 1994; Stange et al., 1995; Stange 1997; Agrell et al., 2000).

One of the issues predicted with climate change is that many pests that previously did not reach damage levels will become damaging. Lower winter temperatures kept most pests under control. However, warmer winter months will eliminate the controlling effect of low temperatures (Bale et al., 2002). With the introduction of new species in agriculture in the new climatic conditions emerging with climate change, these plants will bring their pests with them, and perhaps the pests that come with the new species may be more harmful to the established species of that area.

With global warming, pests will move in the direction of the north and south poles (Bale et al., 2002). This is because very hot and very cold climates are not suitable for the reproduction and spread of pests. Therefore, pests move towards temperate regions. Studies have shown that pests have been spreading at a rate of 3 km per year in the north and south direction since 1960 (Bebber et al., 2013). This means that pests that did not exist in a region before can come to these regions over time. Therefore, the emergence of new pests in addition to existing pests is inevitable.

Elevated CO_2 often leads to an increase in the C/N ratio in plant tissues (Conroy, 1992), which reduces their feeding value for insects. These changes in tissue composition can affect the feeding behaviour and performance of herbivorous insect pests. For optimal plant production, higher soil nitrogen will be required in environments where fertility is increased by increasing atmospheric CO_2, which will act to reduce the C/N nitrogen ratio of plant tissue (Hall and Ziska, 2000).

Global climate change will reduce the effectiveness of pesticides. Increased temperature and ultraviolet rays will cause these pesticides to lose their protective effect on plants more quickly, which will increase the use of pesticides (Noyes et al., 2009). In this regard, the use of pesticides and beneficial organisms of biological origin (biological control) will give better results.

CONCLUSION

That global climate change will not affect every country on every continent. It is stated that temporary production at low latitudes will be affected continuously and negatively by climate change, while northern latitudes will be affected positively or negatively. Although it may become more climatically favourable for some high latitude regions, soil quality and water availability may limit the constantly circulating production sequences in these locations (Reddy and Hodges, 2000). The current analysis results in the fact that it affects national economies and the lives of societies more than today. Measures that can be taken against global climate change can be listed as follows;

• The use of renewable energy sources instead of fossil fuels, causes an increase in the CO_2 concentration in the atmosphere (Omer, 2008).

• The use of smart agriculture systems that ensure optimum use of agricultural inputs (fertilization, irrigation, spraying) and ensure the sustainable use of natural resources (Agrimonti et al., 2021).

• Supporting classical plant breeding with biotechnological methods to protect plant biodiversity and to obtain plant species and varieties suitable for ecology (Pathak and Abido, 2014).

• Protection and development of forests, especially pastures in arid and semi-arid areas, which can bind CO_2 and store it for a long time in global climate change (Reddy and Hodges, 2000; Kalonya, 2022).

• Using data from the plant canopy in climate modelling (Kowalczyk et al., 2006).

• The priority in plant breeding should be increase photosysthesiss optimum, increase water and nitrogen use efficiency in crop plants.

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