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Climate Change Factors: Effect of Increased Co₂ and Temperature on Plant Physiology

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Climate change is one of the major global challenges affecting agricultural productivity and ecosystem stability. Among the drivers of climate change, rising atmospheric carbon dioxide (CO_2) levels and increasing global temperature have strong impacts on plant physiological processes. Elevated CO_2 directly influences photosynthesis, respiration, water-use efficiency, and biomass accumulation. At the same time, higher temperatures change metabolic rates, growth patterns, phenology, and stress tolerance. Although increased CO_2 can boost photosynthesis and plant growth under optimal conditions, the combined effect of higher CO_2 and temperature often leads to complex and sometimes negative outcomes, especially during water and nutrient shortages. This article summarizes how increased CO_2 and temperature affect plant physiology, focusing on their implications for plant growth, crop productivity, and future agricultural sustainability as climate conditions change.

Introduction

Climate change means long-term changes in temperature, precipitation, atmospheric composition, and other environmental conditions mainly driven by human activities like burning fossil fuels, deforestation, and industrialization. One major result of climate change is the steady rise in atmospheric CO_2 levels, which have increased from pre-industrial levels of about 280 ppm to over 420 ppm in recent years. At the same time, global mean surface temperatures have risen significantly, leading to more frequent heatwaves, altered growing seasons, and increased stress on plants. Plants, being stationary organisms, are very sensitive to changes in their environment. CO_2 and temperature are two key factors that directly affect plant physiological processes like photosynthesis, respiration, transpiration, nutrient uptake, and reproductive development. Understanding how plants react to increased CO_2 and temperature is essential for predicting crop performance, ecosystem functioning, and food security in future climate scenarios.

Elevated CO_2 and Plant Physiology

Carbon dioxide is a main ingredient for photosynthesis, and its higher concentration can greatly affect plant growth and metabolism.

Effect on Photosynthesis

Elevated CO_2 generally increases the rate of photosynthesis, especially in C_3 plants, by providing more CO_2 for the enzyme RuBisCO and reducing photorespiration. This process, known as the CO_2 fertilization effect, often leads to more carbohydrate production and biomass accumulation. In contrast, C_4 plants show a smaller response due to their internal CO_2-concentrating mechanisms.

Effect on Stomatal Conductance and Water Use Efficiency

Higher CO_2 levels cause partial closure of stomata, reducing transpiration rates. As a result, plants have better water-use efficiency, which helps them conserve water in dry conditions. However, prolonged stomatal closure may also lower leaf cooling and increase vulnerability to heat stress.

Effect on Growth and Biomass Allocation

Increased CO_2 often encourages vegetative growth, leaf area expansion, and root development. Plants tend to allocate more biomass to their roots, improving nutrient and water acquisition. However, this positive effect may decrease over time due to nutrient limitations, particularly from nitrogen deficiency.

Increased Temperature and Plant Physiology

Temperature is a key factor controlling enzymatic reactions and metabolic processes in plants. Rising temperatures due to climate change have both positive and negative effects on plant physiology.

Effect on Metabolism and Respiration

Higher temperatures increase enzymatic activity, leading to higher respiration rates. While moderate warming can promote growth, excessive temperatures may cause respiratory losses to surpass photosynthetic gains, resulting in lower net productivity.

Effect on Growth and Development

Temperature affects important developmental stages, including seed germination, flowering, fruit set, and maturity. Higher temperatures often shorten the duration of crop growth, leading to early flowering and reduced grain-filling periods, which negatively affect yield and quality.

Effect on Photosynthetic Apparatus

Heat stress can damage chloroplast membranes, disrupt photosystem II, and reduce chlorophyll content. Prolonged exposure to high temperatures can impair photosynthesis and cause oxidative stress from the build-up of reactive oxygen species (ROS).

Combined Effects of Elevated CO_2 and Temperature

In natural environments, plants face changes in CO_2 and temperature at the same time, making the combined effects complex. Increased CO_2 might partially alleviate heat stress by enhancing photosynthesis and water-use efficiency. However, extreme temperature increases often counteract the benefits of CO_2 enrichment by raising respiration rates, speeding up senescence, and disrupting reproductive processes. Additionally, the positive response to elevated CO_2 depends heavily on other factors like soil moisture, nutrient availability, and specific plant traits. In nutrient-poor or dry conditions, the benefits of increased CO_2 may be limited.

Implications for Agriculture and Ecosystems

Changes in plant physiological responses due to increased CO_2 and temperature have major implications for agricultural productivity and natural ecosystems. While some crops may benefit from higher CO_2, heat stress and related factors can lower yield stability and nutritional quality. Furthermore, climate-driven physiological changes may alter plant–pest interactions, weed competitiveness, and ecosystem composition. Creating climate-resilient crop varieties that have better heat tolerance and resource efficiency is crucial for sustaining agricultural production in the face of future climate challenges.

Conclusion

Increased atmospheric CO_2 and rising temperatures are key climate change factors that significantly impact plant physiology. Higher CO_2 can boost photosynthesis, growth, and water-use efficiency, while higher temperatures affect metabolic balance, development, and stress tolerance. The combined effects of these factors are complex and highly dependent on environmental conditions and plant species. A deeper understanding of how plants respond to climate change is vital for improving adaptation strategies and ensuring food security as the world warms.

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