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Effect of Elevated Carbon Dioxide, CO_2 and Temperature on Crop Production: A Review

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Abstract

Plant growth and distribution is limited by the environmental factors. Of the environmental factors temperature and co_2 are the most important. In addition to conductivity of the stomata Water loss by transpiration is also affected by the driving forces for exchange of co_2 from the atmosphere. GHG emissions Have led to changes in the world ‘s climate conditions including temperature and precipitation. In addition to increasing photosynthesis and biomass, another major benefit of rising atmospheric CO_2 is the enhancement of plant water use efficiency. Higher levels of atmospheric CO_2 ameliorate, and sometimes fully compensate for, the negative influences of various environmental stresses on plant growth, including the stress of high temperature. biomass production of modern C3 plants was reduced by 50% when grown at low (180–220 ppm) [CO_2], when other conditions are optimal. occurrence of mild heat (2-3 ^{0}C for more than 13 days) in early spring at reproductive stage caused 28% reduction in the grain yield. crops need almost double amount of water at 2 ^{0}C increase in temperatures at higher elevation of agricultural plains.

Keywords: driving force**,** temperature, co_2, GHG, C3 plants

Introduction

Plant growth and distribution is limited by the environmental factors. If anyone environmental factor is less than the ideal, it will become a limiting factor in plant growth. Limiting factors are also responsible for the geography of plant distribution. Most plant problems are caused by environmental stress, either directly or indirectly. Therefore, it is important to understand the environmental aspects that affect plant growth. And plant growth and development is controlled by Photosynthesis. Photosynthesis is influenced by two categories of factors - external or environmental and internal or plant factors (Alberda, 1977, Goudriaan and Van Laar, 1978, Avery, 1964). External factors could be abiotic or biotic factors. Of the abiotic temperature and co_2 are the most important. The projected climatic effects of the continuously increasing concentrations of CO_2 and other radioactively active trace gasses in the atmosphere have caused concern over the last decades and increasingly attracted scientists' and policy makers' attention (Zenawi, 2016). The expected changes at a global level will be reflected in changed weather conditions in the growing season at regional and local levels that directly affect agriculture and natural vegetation (Solomon, 2007)

Most plants react to the changed atmospheric CO_2 concentration with changed stomatal response, and not only is growth affected but also the transpiration. The complex nature of the physiological response in interaction with micrometeorological processes at the leaf and canopy level requires further attention. Water loss by transpiration is not only affected by the conductivity of the stomata, but also by the driving forces for exchange of the water vapour from the leaf surface to the surrounding atmosphere (Madan et al., 2012, McNaughton and Jarvis, 1991). Therefore, the gradient in partial pressure of the water vapour at the leaf surface is also of importance. All other factors being equal, the existing vapour pressure deficit (VPD) between stomatal cavity and surrounding air the boundary layer, will increase at a reduced transpiration rate, and feed back to stimulate transpiration. The reduced transpiration will cool the leafless, and consequently a rise in temperature in the stomatal cavity and at the leaf surface may occur. Thus, in addition to the global greenhouse effect on air temperature, the temperature at the leaf surface may rise by 0.5 to 1.5 °C (Idso et al., 1987, Morison, 1987).

2. Carbon dioxide/Co_2

Recent studies including those by the Intergovernmental Panel on Climate Change/IPCC, indicate that greenhouse gas(GHG) emissions and resultant atmospheric concentrations Have led to changes in the world ‘s climate conditions including temperature and precipitation(Solomon, 2007, Zenawi, 2016). The implications of climate change and atmospheric GHG concentrations for crop yields, and economic welfare has stimulated many studies. A wide variety of findings have arisen regarding the effect of climate change on crop yields and proved that climate change alters mean crop yields (Schlenker and Roberts, 2009, Jain et al., 2010).

The response of seed production to CO_2 concentration [CO_2] is known to vary considerably among C3 annual species. seed production is limited by nitrogen availability, an increase in seed mass per plant results from increase in seed nitrogen per plant and/or from decrease in seed nitrogen concentration/[N]. Meta-analysis reveals that the increase in seed mass per plant under elevated [CO_2] is mainly due to increase in seed nitrogen per plant rather than seed [N] dilution (Reddy et al., 2010, Wang et al., 2012). Nitrogen-fixing legumes enhanced nitrogen acquisition more than non-nitrogen-fixers, resulting in a large increase in seed mass per plant. These differences in CO_2 response of seed production among functional groups may affect their fitness, leading to changes in species composition in the future high [CO_2] ecosystem (Taub, 2010).

2.1 Extreme high Carbon dioxide /Co_2

Typically, doubling of the air's CO_2 content above present-day concentrations raises the productivity of most herbaceous plants by about one-third; and this positive response occurs in plants that utilize all three of the major biochemical pathways (C3, C4, CAM) of photosynthesis. In addition to increasing photosynthesis and biomass, another major benefit of rising atmospheric CO_2 is the enhancement of plant water use efficiency. Studies have shown that plants exposed to elevated levels of atmospheric CO_2 generally do not open their leaf stomatal pores (through which they take in carbon dioxide and give off water vapor) as wide as they do at lower CO_2 concentrations (Backlund et al., 2008), In addition, they sometimes produce less of these pores per unit area of leaf surface. Both of these changes tend to reduce most plants' rates of water loss by transpiration. As a result, the amount of carbon gained per unit of water lost per unit leaf area or water-use efficiency increases dramatically as the air's CO_2 content rises.

Higher levels of atmospheric CO_2 ameliorate, and sometimes fully compensate for, the negative influences of various environmental stresses on plant growth, including the stress of high temperature (Reddy et al., 2010, Taub, 2010).

Although co_2 uptake rate and [co_2] is higher because of decarboxylation of malate in bundle sheath cell in c4 plants but in high [co_2] environment c3 plants photosynthesis in higher rate(Reddy et al., 2010).

2.2 extreme Low Carbon dioxide /Co_2

In C3plants, low [CO_2] affects net photosynthetic rates by reducing the rate of carboxylation of Rubisco resulting from substrate limitations and through higher photo respiration rates (Royer et al., 2007). And many studies proved that Photorespiration is increased at low [CO_2] because both CO_2 and O_2 compete for the same active site of Rubisco. A reduction in [CO_2] ⁄ [O_2] enhances oxygenation, resulting in carbon loss to the plant. Note that unlike [CO_2], [O_2] has remained unchanged in the atmosphere for at least the last several million years.studies have shown that the average biomass production of modern C3 plants was reduced by 50% when grown at low (180–220 ppm) [CO_2], when other conditions are optimal (Sage and Coleman, 2001).

It has been hypothesized that plants grown at low [CO_2] would partition a higher proportion of biomass to above-ground than to below-ground structures; this response increases LAR and enhance overall investment in carbon assimilation under limiting [CO_2] (Sage and Coleman, 2001). A variety of studies have found support for this idea, including (Dukes, 2000) who showed that the A. ophrasti partitioned a higher proportion of bio-mass to shoots relative to roots at 150 than at 350 ppmCO_2 (root: shoot mass = 0.17 vs 0.34, respectively).

3. Temperature

Temperature is one of the major environment factors affecting the growth, development and yields of crops especially the rate of development. crops have basic requirement for temperature to complete a specific phenol phase or the whole life cycle. On the other hand, extremely high and low temperature can have detrimental effects on crop growth, development and yield particularly at critical phenophases such as anthesis. (Madan et al., 2012) pointed out that the effects of hot temperature episodes close to the time of anthesis were of more importance to the yield of many crops than the effects of the increase in mean seasonal temperature of about 2◦C. most of crops do not respond if temperature is beyond the limit (5-40°c) (Prueger and Hatfield, 2015)

3.1 Extreme High temperature

Climate change (high temperature) has been causing a drastic change in weather patterns and adversely affects crop yield. Large variability has been observed in the precipitation and thermal regimes but discussion will be focused on thermal one here. Some recent examples in different parts of the world are stated below.

- Goswami et al. (2006) diagnosed the causes of reduction in wheat yield in India while the visible crop condition was the best. It was pointed out that the occurrence of mild heat wave (13 days above normal (2-3°C) temperatures) in early spring at reproductive stage caused 28%reduction in the grain yield of wheat.
- In Pakistan, February 2006 was 2-4°C warmer than normal and significant yield reductions were reported. Wheat was in the grain formation phase, high temperatures accelerated the development as the required heat units were met immediately. The grains could not gain proper size and weight rather they were shriveled hence resulted in reduced yield.
- Smith et al. (2001) reported that yield increased up to 29°C for corn, 30°C for soya bean and 32°C for cotton. Higher temperatures are harmful. It was predicted that 30-46% reduction in yield if temperature is beyond.

3.2. Effect of Future Rise in Temperature on Crop Water Requirement

Crop water requirement is directly related to the evaporative demand of the atmosphere in which the crop is grown. The evaporative demand of the atmosphere is direct measure of crop evapotranspiration which is not a directly measurable physical quantity rather it is estimated by using empirical formulae. Such estimations differ widely on temporal and spatial scales as well as formula to formula.(Bandiera et al., 2009) tested four methods of estimation of crop evapotranspiration commonly used in south Asian region for different agro climatic zones of Pakistan. Due to global warming, the temperatures are expected to increase over the present limits at a variable rate simultaneously the water demand of the crops will also increase. Rasul et al. (2011) computed the future water requirement of the crops generally grown indifferent climatic zones of Pakistan taking 1°C, 2°C and 3°C rise in temperature, found that an average increase in crop water demand 11%, 19% and 29% respectively. It was further elaborated that the water requirement of crops will increase at a higher rate than the northern sub-mountainous agricultural plains located in active monsoon zone. However, the crops need almost double amount of water at 2°C increase in temperatures at higher elevation agricultural plains of northern and western mountains. A good news for those small land holding farmers will be double crop season as the dormancy period will be significantly reduced in the length and the persistence.

3.3. Extreme Low temperature

Chilling sensitive plants are those that suffer a dramatic and often slowly reversible, damaging, inhibition of plant processes at low temperatures usually below 15 °C(Chaumont et al., 1995). Grapevines, which are often grown in cool climates for premium quality wine production, are frequently exposed to chilling temperatures well below 20 °C. Growth cabinet studies have revealed that grape shoot and root growth and fruiting yields are significantly reduced by large decreases in temperature(Buttrose, 1969). studies have claimed that both non-acclimated and acclimated grapevines are sensitive to chilling temperatures but these investigations focused principally on the chilling sensitivity of photosynthesis (Chaumont et al., 1995). Other studies have demonstrated a linear relationship between photosynthetic capacity and plant growth, measured as the accumulation of dry weight over time in potted grapevines. Whole canopy photosynthesis was directly correlated with total dry mass accumulation of potted Chambourcin grapevines (Howell et al., 1997). and (Ferrini et al., 1995) showed that the relationship between photosynthetic capacity and total dry mass accumulation was linear and that total shoot length mirrored the accumulation of total dry mass. In that study grapevines treated at below optimum temperature (20 °C) exhibited reduced photosynthetic capacity and thus reduced carbon gain and growth (Ferrini et al., 1995).

4. Interactive effects of elevated CO_2 and growth temperature

Determining effects of elevated CO_2 on the tolerance of photosynthesis to acute heat-stress (heat wave) is necessary for predicting plant responses to global warming, as photosynthesis is thermo labile and acute heat-stress and atmospheric CO_2 will increase in the future (Avery, 1964, Alberda, 1977). In C3 species, basal thermotolerance of net photosynthesis (P(n)) was increased in high CO_2, but in C4 species, P(n) thermotolerance was decreased by high CO_2 (except Zea mays at low growth temperatures/GT); (Reddy et al., 2010).Though high CO_2 generally decreased stomatal conductance, decreases in P(n) during heat stress were mostly due to non-stomatal effects. Photosystem II (PSII) efficiency was often decreased by high CO_2 during heat stress, especially at high GT; CO_2 effects on post-PSII electron transport were variable. Thus, high CO_2 often affected photosynthetic theromotolerance, and the effects varied with photosynthetic pathway, growth temperature, and acclimation state. Most importantly, in heat-stressed plants at normal or warmer growth temperatures, high CO_2 may often decrease, or not benefit as expected, tolerance of photosynthesis to acute heat stress. Therefore, interactive effects of elevated CO_2 and warmer growth temperatures on acute heat tolerance may contribute to future changes in plant productivity, distribution, and diversity. (Julius et al., 2008, Kruk and Levinson, 2008, Usda, 2007, Madan et al., 2012).

Conclusion

Greenhouse gas(GHG) emissions and resultant atmospheric concentrations Have led to changes in the world 's climate conditions including temperature and precipitation. doubling of the air's CO_2 content above present-day concentrations raises the productivity of most herbaceous plants by about one-third (if other climate condition is kept normal). low [CO_2] affects net photosynthetic rates by reducing the rate of carboxylation. extremely high and/or low temperature (beyond 5 - 40°C) can have detrimental effects on crop growth, development and yield particularly at critical phenophases such as anthesis. crops need almost double amount of water at 2°C increase in temperatures at higher elevation of agricultural plains. effects of elevated CO_2 and warmer growth temperatures on acute heat tolerance may contribute to future changes in plant productivity, distribution, and diversity.

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