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A Review : Impact of Elevated CO_2 Concentration in Horticulture Crop Production

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ABSTRACT

Studies have shown that higher concentrations of atmospheric carbon dioxide affect crops in two important ways: they boost crop yields by increasing the rate of photosynthesis, which spurs growth, and they reduce the amount of water crops lose through transpiration. Plants transpire through their leaves, which contain tiny pores called stomata that open and collect carbon dioxide molecules for photosynthesis. During that process they release water vapor. As carbon dioxide concentrations increase, the pores don't open as wide, resulting in lower levels of transpiration by plants and thus increased water-use efficiency. Thus the purpose of this review paper is to summarize all the factor affecting to the horticultural crops through the elevated corbon dioxide in environment.

Keywords Impact, Elevated CO_2, Crop, Production, Photosynthesis.

INTRODUCTION

The level of CO_2 in the atmosphere is rising at an unprecedented rate, has increased from 280 ppm at the beginning of the industrial revolution (1750) to ≈380 ppm today and is expected to double preindustrial levels some time during this century (Keeling and Whorf 2001, Neftel *et al.* 1985). The extent of growth and yield responses of plants to elevated CO_2 depends on the photosynthetic pathway. Crops with C_3 photosynthesis will respond markedly to increasing CO_2 concentrations. Common C_3 crops are small grain cereals (wheat, rice, barley, oat and rye) ; grain legumes or pulses (soybean, peanut, various beans and peas) ; root and tuber crops (potato, cassava, sweet potato, sugar beet, yams) ; most oil, fruit, nut, vegetable and fiber crops ; and temperate-zone (cool-climate) for age and grassland species. In contrast, plants with C_4 photo synthesis will respond little to rising atmospheric CO_2 because a mechanism to increase the concentration of CO_2 in leaves causes CO_2 saturation of photosynthesis at current ambient concentrations. Common C_4 crops are maize (corn), sugarcane, sorghum, millet, and many tropical and subtropical zone (warm-climate) grass species. This article focuses on responses to elevated CO_2 and increased temperature of C_3 crops. Response patterns

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are similar, but not the same, across a broad range of species and conditions (Allen *et al.* 2004).

In the recent years CO_2 has rapidly increased to about 370 µmol mol1 at present. At present rates of emissions, CO_2 is predicted to more than double by the end of 21st century (Houghton *et al.* 2001). These changes in atmospheric CO_2 along with other greenhouse gases (water vapor, methane, nitrous oxide, sulfurdioxide) can potentially change global climate. At the present rate of CO_2 increase, various atmospheric general circulation models have predicted that the near-surface temperature of the earth could increase as much as 3 to 6°C (Houghton *et al.* 2001). Changes in CO_2 and associated changes in global temperature can cause significant changes in crop production. In this review, we will summarize the responses of soybean, dry bean, peanut and cowpea to elevated CO_2 and its interaction with temperature. Among all the legume crops, soybean is the most widely studied crop species with reference to responses to elevated CO_2. Because of the breadth of available literature, most of the examples are drawn from soybean; however, species differences between these legume crops will be highlighted and discussed as necessary.

As CO_2 is responsible for 61% of global warming, a doubling of the atmospheric CO_2 and a rise in other so-called greenhouse gases (methane, nitrous oxide, chloro-fluorocarbons) would increase the mean global temperature, possibly as much as 4.5 to 6°C. In addition, shifts in regional precipitation patterns as a result of rising atmosphere (CO_2) will probably result in decreased soil water availability in many areas of the world (Keeling *et al.* 1995, Wigley and Raper 1992, Allen 1994). Atmospheric CO_2 is an essential compound for life on Earth. Through photosynthesis plants obtain carbon for their growth and provide sustenance for other livingthings, ourselves included. In photosynthesis, solar energy is absorbed by a system of pigments and inorganic atmospheric CO_2 is fixed and reduced into organic com-pounds. Reduction of carbon is a major function of photosynthesis and is quantified by realizing that plant organic matter is about 45% carbon on a dry weight basis (Mnibur rahman *et al.* 2015).

Impact of CO_2 on water use efficiency

The rising concentration of CO_2 in the atmosphere is considered to be one of the main driving forces of global climate change. Studies have shown that CO_2 concentrations increased from 280 µmol·mol−1 in the industrial revolution to 388 µmol·mol−1 today, and are expected to increase to 700 µmol·mol−1 by the end of the twenty-first century. Global warming caused by increased CO_2 concentrations will have a profound impact on the environment and climate change (Fangmeier *et al.* 2000, Aranjuelo *et al.* 2011, Yin *et al.* 2017). As a substrate for plant photosynthesis, higher CO_2 concentrations will affect plant photosynthesis and their physiological and biochemical processes (Prasad *et al.* 2009), by increasing intercellular CO_2 and carboxylation efficiency, reducing photorespiration (Bowes 2003, Ainsworth and Long 2005, Zhang and Dang 2005, Stiling *et al.* 2013), increasing WUE (Fleisher *et al.* 2008, Pazzaglia *et al.* 2016, Varga *et al.* 2017), increasing the content of soluble sugar and starch (Bindi *et al.* 2001, Sun *et al.* 2012) and enhancing the activity of antioxidant enzymes (SOD and CAT) (Marabottini *et al.* 2001, Schwanz and Polle 2001). Other researchers have reported that increased CO_2 con concentrations could lead to a decrease in stomatal density (Xu *et al.* 2017) and conductance (Ainsworth and Long 2005), the reduction of partial pressure of oxygen in cells, and a decrease in plant leaf respiration rate (Gifford 1995, Ziska and Bunce 1998). Rising CO_2 promotes plant photosynthesis and growth and increases crop yield (Murray *et al.* 2000, Li *et al.* 2007), but other studies have demonstrated that high CO_2 concentrations change the source sink balance of crops and affect the operation of organic matter from the vegetative organ to grain (Biswas *et al.* 2013, Bourgault *et al.* 2013). The decreased transpiration rate caused by reduced stomatal conductance indirectly limits nutrition uptake for plants, affecting the growth and quality of crops (Loladze 2002, Högy and Fangmeier 2008, Högy *et al.* 2009, Myers *et al*. 2014, Li *et al.* 2016, Dong *et al.* 2018). Global climate change caused by the increase in CO_2 concentrations causes extreme weather, such as drought, and these jointly affect the physiological and ecological processes of plants (Jiang *et al*. 2016, Xu *et al.* 2016). Drought stress is one of the important limiting factors for agricultural production and leads to a decline in crop yield and quality (Ye *et al.* 2018, Zhang CO_2 2019). Plant photosynthesis is a process that is sensitive to drought. Under drought stress, wilting and curling of plant leaves and reduced chlorophyll content occur frequently. More specifically, drought stress could suppress a series of physiological processes, such as the decrease or closure of stomatal conductance, the inhibition of chlorophyll synthesis or the acceleration of degradation, the reduction of photosynthetic enzyme activity, and reduced photosynthetic carbon assimilation (Pukacki and Kamińska-Rożek 2005, Nikolaeva *et al.* 2010, Albert *et al.* 2011). Moreover, drought stress also results in the reduction of PSII and PSI activities, the resistance of photosynthetic electron transfer and the accumulation of excess energy (Schansker *et al.* 2005, Zhang *et al*. 2018b). Excess electrons and energy may lead to the increase of reactive oxygen species (ROS) content and excessive ROS breaks the balance of redox in plants and causes peroxidation membrane damage (Gill and Tuteja 2010, Wang *et al.* 2017). Many studies have shown that increased CO_2 concentrations can alleviate the inhibition of abiotic stress on plant growth and physiological function (Shanmugam *et al.* 2013, Medina *et al.* 2016, Li *et al.* 2017, Wei *et al*. 2018). This increase causes a rise of intercellular CO_2 concentration (Ci), which could compensate for the CO_2 restriction caused by the decrease of stomatal conductance under stress (Morison and Gifford 1983). It also reduces transpiration by reducing the stomatal conductance (Gs), thus improving the WUE of plant leaves under stress (Fleisher *et al*. 2008, Pazzaglia *et al.* 2016, Varga *et al.* 2017). Rising CO_2 increases carbohydrate concentration under drought stress, resulting in the enhancement of cell osmotic potential and drought resistance of plants (Dong *et al.* 2015). The leaves of mulberry trees (*Morus alba* L.) can not only be used as silkworm feed, but also have antioxidants with important medicinal value (Katsube *et al*. 2006). In addition, mulberry has strong drought resistance and is an excellent tree species for sand fixation and water and soil conservation, which has important economic and ecological value (Sarkar *et al*. 2017). However, there are no reports on the photosynthetic functions of mulberry seedling leaves under drought stress with increased CO_2 concentrations, and most of the studies on plant photosynthesis have focused on the stoma and photosynthetic gas exchange. There are few studies of the PSII function of plant light reactions under this condition. Therefore, under the condition of natural drought, the effects of rising CO_2 on photosynthetic gas exchange of mulberry seedling leaves, instantaneous WUE, and PSII function were studied in this paper to provide some basic data for the mechanism of plant photosynthesis under drought stress.

Impact of elevated CO_2 on vegetables

Elevated atmospheric CO_2 (eCO_2) enhances the yield of vegetables and could also affect their nutritional quality. We conducted a meta-analysis using 57 articles consisting of 1,015 observations and found that eCO_2 increased the concentrations of fructose, glucose, total soluble sugar, total antioxidant capacity, total phenols, total flavonoids, ascorbic acid and calcium in the edible part of vegetables by 14.2%, 13.2%, 17.5%, 59.0%, 8.9%, 45.5%, 9.5% and 8.2%, respectively, but decreased the concentrations of protein, nitrate, magnesium, iron and zinc by 9.5%, 18.0%, 9.2%, 16.0% and 9.4%. The concentrations of titratable acidity, total chlorophyll, carotenoids, lycopene, anthocyanins, phosphorus, potassium, sulfur, copper and manganese were not affected by eCO_2. Furthermore, we propose several approaches to improving vegetable quality based on the interaction of eCO_2 with various factors, including species, cultivars, CO_2 levels, growth stages, light, O_3 stress, nutrient, and salinity. Finally, we present a summary of the CO_2 impact on the quality of three widely cultivated crops, namely, lettuce, tomato and potato. (Dong *et al.* 2018).

There have been many studies of the storage of fruit and vegetables since the report of Kidd and West (1927) concerning the beneficial effects of high CO_2/low O_2 storage (controlled atmosphere CA). Since CO_2 is a product of respiration, it would be expected that respiration rate would decrease as CO_2 concentration in the atmosphere increases (Hewer 1987). Succinic acid accumulates and the activities of enzymes involved in its metabolism decrease in several fruits stored in high CO_2, which is indirect evidence for this possibility (Biale 1960, Kader 1986). Carbon dioxide inhibits C_2H_4 action competitively and helps regulate C_2H_4 biosynthesis (Burg and Burg

1967). Therefore, some of the benefits of storage in a high- CO_2 atmosphere arise when C_2H_4 production or C_2H_4-mediated reaction is inhibited (Herner 1987). It is not well-known how high CO_2, affects respiration and C_2H_4 synthesis, these two may be related (Sisler and Wood 1988).

The response of crops to elevated atmospheric CO_2 concentrations (Ca) is of great concern for horticultural vegetable production in greenhouse facilities, where Ca levels are often artificially elevated. To elucidate the long-term effect of the elevated Ca on canopy photosynthesis and growth, we conducted long-term continuous measurements of the canopy photosynthesis (A) and leaf area index (L) of hydroponically grown spinach canopies under elevated Ca (approximately 800 μmol mol^{-1}) and ambient Ca (approximately 400 μmol mol^{-1}) treatments by combining the open chamber method and image analysis of the top of view of canopies. There existed a positive feedback loop between A and L, where an increase in L caused an increase in A, which subsequently accelerated the increase in L. The enhancing effect of elevated Ca on A, which was evaluated with enhancement ratios (i.e., A in the elevated Ca treatment divided by A in the ambient Ca treatment,Aelev/Aamb), showed a short-term increase under high-light conditions during the daytime and a long-term increase with canopy growth toward the harvest. The long-term increase in Aelev/Aamb was attributed to the enhancement of Aelev brought on by not only the short-term enhancing effect of elevated Ca but also the more rapidly increasing and thus larger L in the elevated Ca treatment compared with that in the ambient Ca treatment. Both the longterm increase in Aelev/Aamb and the more rapidly increasing L in the elevated Ca treatment were caused by the "compound interest effect" of elevated Ca, where the enhancing effects of elevated Ca on A and L were gradually amplified over a long-term period through the positive feedback loop between A and L. This compound interest effect of elevated Ca also caused a long-term increase in canopy nighttime respiration in proportion to daytime photosynthesis. Through these changes in the canopy-scale carbon balance, the compound interest effect detected in the elevated Ca treatment likely contributed to a substantial increase in the final aboveground dry weight at the harvest time. This study highlights the importance of the long-term compound interest effect of elevated Ca on canopy photosynthesis, carbon balance and growth (Nomura *et al*. 2021).

Impact of CO_2 on fruit

Six year-old Japanese pear (*Pyrus seratina* Reheder cv Kosui) trees grafted on *P. serotina* cv. Nihonyamanashi were grown in containers filled with Granite Regosol under glasshouse conditions. At different stages of fruit growth, pear trees were exposed to an elevated CO_2 concentration (130 Pa CO_2) along with a control (35 Pa CO_2). For one group of plants, CO_2 enrichment was applied for 79 d from 52 d after full bloom (DAB) to fruit maturity (long-term CO_2 enrichment) and for another group the same treatment was applied for 35 d from 96 DAB to fruit maturity (short-term CO_2 enrichment). The effects of the elevated CO_2 concentration on vegetative growth, mineral contents and fruit production and quality were examined. Long-term CO_2 enrichment enhanced vegetative growth, without any significant effect on the mineral contents in either flower bud or fruit except for a remarkable increase in the K content. Long-term CO_2 enrichment increased the fruit size and fresh weight, but had no significant effect on the fruit quality. On the other hand, the short-term CO_2 enrichment did not induce any significant change in the fruit size but increased the fruit sugar concentration. Along with the reduction of the sorbitol concentration in fruit, the fructose and sucrose concentrations increased and these changes occurred earlier at elevated CO_2 than at ambient CO_2 concentrations. From these results, we concluded that the effect of CO_2 enrichment on fruit growth varies depending upon the growth stages of fruit : During the initial and fruitlet stages when fruit expansion occurs, CO_2 enrichment increases the fruit size, whereas, during maturation when fruit expansion has slowed down and sugar accumulation in fruit is active, it increases the fruit sugar concentration (Ito *et al.*1999).

The respiration rate (O_2 uptake) and the rate of C_2H_4. Production were measured before, during and after 24 hrs of treatment with 60% CO_2 (20%

O_2) in 18 kinds of fruits and vegetables by use of an automated system connected to a microcomputer. High CO_2 decreased respiration only in climacteric fruit and broccoli, which were producing C_2H_4. Ethylene production decreased with CO_2, treatment of peaches, tomatoes, and broccoli, but that of bananas increased. In five nonclimacteric fruits (three citrus species, grapes and Japanese pears) and several vegetables (carrots, onions, cauliflower and cabbage), in which C_2H_4 production was not detected, high CO_2 affected respiration little, if at all. When eggplants, cucumbers, podded peas, spinach and lettuce were treated with high CO_2, C_2H_4 production began and respiration increased. These results indicate that the respiratory responses of harvested horticultural crops to high CO_2 might be mediated by the effects of CO_2 on the action and/or synthesis of C_2H_4 (Kubo *et al.* 1990).

Impact of CO_2 on photosynthesis

The CO_2 concentration outdoors continues to increase and is now 400 ppm and even higher near urban areas. While this increase has negative effects on the environment, it is a main ingredient for photosynthesis and thus subtly increases plant growth. However, the CO_2 concentration inside a greenhouse is often not at 400 ppm. For example, when greenhouses are closed during the winter and filled with crops, CO_2 is used by plants and the concentration becomes low, perhaps as low as 200 ppm. A low CO_2 concentration has two consequences : Photosynthesis is reduced and the light saturation point is decreased (The light saturation point is the intensity at which additional increases in light do not increase photosynthesis). This means the value of supplemental lighting is marginalized at a low CO_2 concentration. Photosynthesis increases as CO_2 increases until some saturating concentration, which is typically around 1,000 ppm. Enriching the air with CO_2 enables plants to more effectively utilize light, resulting in an increase in the light saturation point. Just as with supplemental lighting, the law of diminishing returns applies to CO_2 supplementation. Increasing the CO_2 concentration from 300 to 500 ppm causes a much greater increase in photosynthesis than increasing the CO_2 from 800 to 1,000 ppm. In the United States, few growers of ornamentals use supplemental CO_2, but it is commonly used in greenhouse production of vegetables, especially for tomatoes (Erik runkle 2015).

CONCLUSION

In general, increased CO_2 increases plant growth (both above and below ground) and improves plant water relations (reduces transpiration and increases WUE). It is likely these benefits will also occur for horticultural plants, but data to support this are lacking relative to crop and forest species. In addition to basic research on the response of diverse horticultural species to future levels of atmospheric CO_2, it may become crucial to breed or screen varieties and species of horticultural plants for increased drought tolerance as a result of predicted changes in precipitation patterns. How CO_2 induced changes in plant growth and water relations will impact the complex interactions with pests (weeds, insects and diseases) is a deficient area of research not only for horticulture, but for plants in general. All this information is needed to develop best management strategies for the horticulture industry to successfully adapt to future environmental change.

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