The Pharma Innovation Journal 2022; 11(12): 314-317

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2022; 11(12): 314-317

www.thepharmajournal.com
Received: 18-10-2022
Accepted: 23-11-2022

**Akhilesh Kushwaha**
Department of Horticulture, Sam Higginbottom University of Agriculture, Technology and Sciences. Naini, Prayagraj, Uttar Pradesh, India

**Vijay Bahadur**
Department of Horticulture, Sam Higginbottom University of Agriculture, Technology and Sciences. Naini, Prayagraj, Uttar Pradesh, India

**Prachi Tamrakar**
Department of Horticulture, Sam Higginbottom University of Agriculture, Technology and Sciences. Naini, Prayagraj, Uttar Pradesh, India

**Corresponding Author:**
**Akhilesh Kushwaha**
Department of Horticulture, Sam Higginbottom University of Agriculture, Technology and Sciences. Naini, Prayagraj, Uttar Pradesh, India

# Impact of increased $CO_2$ level on Horticultural crops

**Akhilesh Kushwaha, Vijay Bahadur and Prachi Tamrakar**

**Abstract**
Elevated atmospheric $CO_2$ enhances not only the yield of horticultural crop but could also affect their nutritional quality. Plant growth can be stimulated by elevation of $CO_2$; photosynthesis increases and economic yield is often enhanced. The application of more $CO_2$ can increase plant water use efficiency and result in less water use. After reviewing the available $CO_2$ literature, we offer a series of priority targets for future research, including: 1) a need to breed or screen varieties and species of horticultural plants for increased drought tolerance; 2) determining the amount of carbon sequestered in soil from horticulture production practices for improved soil water-holding capacity and to aid in mitigating projected global climate change; 3) determining the contribution of the horticulture industry to these projected changes through flux of $CO_2$ and other trace gases (i.e., nitrous oxide from fertilizer application and methane under anaerobic conditions) to the atmosphere; and 4) determining how $CO_2$-induced changes in plant growth and water relations will impact the complex interactions with pests (weeds, insects, and diseases). Such data are required to develop best management strategies for the horticulture industry to adapt to future environmental conditions.

**Keywords:** $CO_2$, Horticultural crops, photosynthesis increases and economic yield

## Introduction

Cultural management of fruit trees under plastic house or glasshouse conditions to improve the fruit quality and to obtain maturation of earlier fruit has become a common practice. Under such cultural conditions, environmental factors including $CO_2$ concentration, temperature, water status in soil, etc. may affect vegetative and fruit growth as well as fruit quality. Although numerous researchers have studied the effect of $CO_2$ enrichment on fruit production, the effect on fruit quality is not well documented. $CO_2$ enrichment enhances photosynthesis and leads to a higher biomass production and economic yield in C3 plants (Kimball 1983; Bowes 1993) [22, 4]. The response of the photosynthetic activity to $CO_2$ enrichment differs between herbaceous plants and tree species. In the former, initial stimulation of photosynthesis by short-term $CO_2$ enrichment decreases or disappears during long-term $CO_2$ enrichment (Masuda *et al.* 1989; Idso and Kimball 1991; Bowes 1993; Makino 1994) [28, 15, 17, 4, 27]. However, no such effect on the regulation of photosynthesis has been observed in trees (Idso *et al.* 1991; Idso and Kimball 1992) [16, 15, 17]. Besides photosynthesis, mineral supply, and sink activity are assumed to be involved in the differential response to long-term $CO_2$ enrichment among plant species (Arp 1991; Idso *et al.* 1991; Fisher *et al.* 1997) [2, 15, 17, 8].

Elevated $CO_2$ has frequently been demonstrated to increase the yield of various crops, including vegetables (Kimball, 1983; Long *et al.*, 2004) [22, 26]. Elevated $CO_2$ (from 355 to 800-900 μmol $mol^{-1}$) increased the yield of lettuce, carrot, and parsley by 18%, 19%, and 17%, respectively. 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 sometime during this century (Keeling and Whorf, 2001; Neftel *et al.*, 1985) [23, 33]. This global rise can be primarily attributed to fossil fuel burning and land use change associated with industrial and/or population expansion (Houghton *et al.*, 1990) [14]. This rise, along with other trace gases, is widely thought to be a primary factor driving global climate change (IPCC, 2007) [19]. Aside from the debate on anthropogenic-driven climate change, vegetation will be directly impacted and research has shown that plants respond positively to elevated $CO_2$ (Amthor, 1995) [1]. 314Most of this has focused on agricultural and forest species with limited work on specialty crops associated with horticulture. Horticulture is a diverse industry (encompassing many small businesses) that impacts the landscape of both rural and urban environments and has an economic impact of $148 billion annually in the United States. We will attempt to discuss the effects of the rise in atmospheric $CO_2$ concentration on plant growth and water relations with a focus toward implications for horticultural production systems with suggestions for future research areas.

**Effect of $CO_2$ enrichment on vegetative and fruit growth**

It has been reported that photosynthesis is enhanced by elevated $CO_2$ concentration in the atmosphere depending on the growth conditions such as pot size and nutrient supply (Sage 1994) [35]. The trees which are grown in containers with an adequate size and since a sufficient amount of fertilizer are applied, it appears that root growth and nutrient supply did not affect the response to $CO_2$ enrichment.

It was observed that $CO_2$ enrichment stimulated the growth of both vegetative parts and fruits which proceeded simultaneously after blooming, particularly in the former. 13C tracer experiments revealed that when the sink activity in fruit increased with maturation, fruit predominantly imported photo assimilates. These results together with the fact that elevated $CO_2$ enhanced the photosynthetic activity (Kimball 1983; Bowes 1993; Makino 1994) [22, 4, 27], suggest that at ambient $CO_2$ concentration, vegetative growth is more severely suppressed due to the insufficient supply of photosynthates. This fact implies that fruit has a higher activity as sink for photo assimilates than vegetative parts at the maturation stage of fruits.

It was observed that although elevated $CO_2$ concentration had no significant effect on bud formation, it promoted the formation and development of flower buds (data not shown) and also increased mature fruit weight. Similar phenomena were observed in tomato: $CO_2$ enrichment had no significant effect on the number or development of flowers, while it increased significantly both fruit number and fruit weight (Knecht and O'Leary 1974) [24]. These results suggest that $CO_2$ enrichment is more effective in stimulating fruit growth than development including the formation of buds and flowers. This may imply that $CO_2$ enrichment contributes to plant biomass production mainly through the enhancement of photosynthesis and photo assimilate translocation rather than through the formation of reproductive organs by stimulating the functions of plant growth regulators.

**Sugar metabolism and $CO_2$ enrichment**

It was observed that although long-term $CO_2$ enrichment increased the average fruit size, it had no significant effect on fruit quality including TSC, acidity, and hardness, whereas, short-term $CO_2$ enrichment during maturation of fruit increased the fruit sugar concentration. Our results suggest that the effect of $CO_2$ enrichment on fruit production and quality differs depending upon the stages of fruit growth: $CO_2$ enrichment during the initiation and fruitlet stages increases fruit size, while the same treatment during maturation of fruit increases the fruit sugar concentration. It has been reported that the effect of $CO_2$ enrichment on plant growth is markedly dependent on the plant age (Neales and Nicholls 1978; Ingvardsen and Veierskov 1994) [32, 18]. However, the reason why the total sugar concentration in fruit increases by the elevation of the $CO_2$ concentration during the maturation of fruit is not thoroughly understood. Nevertheless, based on our results, the increase in the sugar concentration in fruit by $CO_2$ enrichment appears to be due to extended maturation and enhancement of the sugar metabolism. It is generally recognized that sorbitol, a major translocation form of photo assimilates, is converted to mainly fructose, and glucose, then finally to sucrose in Japanese pear (Yamaki and Moriguchi 1989) [37]. Furthermore, sorbitol translocated into fruit has been reported to be converted to fructose and glucose by the N AD+ -dependent sorbitol dehydrogenase and sorbitol oxidase enzymes, respectively and then from these sugars sucrose is synthesized by the sucrose-metabolizing enzymes such as sucrose synthase and sucrose-phosphate synthase (Moriguchi *et al*. 1992) [29].

**Impact of $CO_2$ on Vegetable Crop**

Generally, $eCO_2$ (700-1000 μmol $mol^{-1}$) can promote the yield of vegetables (Gruda and Tanny, 2014) [10]. The sources of $CO_2$ have changed from traditional straw bales and organic soils to relatively pure $CO_2$ from industrial waste or $CO_2$ generators (Gruda, 2005) [12]. Elevated $CO_2$ has frequently been demonstrated to increase the yield of various crops, including vegetables (Kimball, 1983; Long *et al*., 2004) [22, 26]. Elevated $CO_2$ (from 355 to 800-900 μmol $mol^{-1}$) increased the yield of lettuce, carrot, and parsley by 18%, 19%, and 17%, respectively. Optimizing other environmental factors with $eCO_2$ further increased plant productivity and yield (Kirschbaum, 2011) [25]. Elevated $CO_2$ (900 μmol $mol^{-1}$) with additional light (ambient + 100 μmol $m^{-2} s^{-1}$ photosynthetically active radiation or PAR) increased the early yield of tomato and pepper by 15% and 11%, respectively (Fierro *et al*., 1994) [9]. Elevated $CO_2$ (600-700 μmol $mol^{-1}$) increased the average root dry mass of sugar beet by 26% in high N availability (10 mM $NO_3^-$) and by 12% in 1 mM $NO_3^-$ (Demmers-Derks *et al*., 1998) [5]. More examples of yield benefits for other vegetable crops are reviewed by Gruda (2005) [12].

There is less information on the effect of $CO_2$ concentration on the nutritional quality of vegetables (Gruda, 2005; Moretti *et al*., 2010) [12]. Elevated $CO_2$ promotes soluble sugar accumulation in the edible parts of vegetables. The increased $CO_2$ fixation under $eCO_2$ promotes the synthesis of triose phosphate in leaves (Long *et al*., 2004) [26], which can be further transformed into other carbohydrates, e.g., glucose, fructose, and sucrose.

The meta-analysis showed that $eCO_2$ increased the concentrations of glucose by 13.2%, fructose by 14.2%, sucrose by 3.7% (at $p = 0.07$), and total soluble sugar by 17.5% in terms of all vegetables (Jinlong Dong *et al* 2018) [6] The increment of total soluble sugar in leaf (an organ for carbohydrate synthesis) under $eCO_2$ was the greatest (36.2%) among all the classes of vegetables. The increment can reach 38-188% in the leaves of Chinese cabbage and 16-53% in the leaves of oily sowthistle (Jin *et al*., 2009) [20]. Compared to leafy vegetables, the increments of total soluble sugar were less in fruit and root vegetables, and were 8.5% and 16.3%, respectively. This indicates that the synthesized carbohydrates in leaves cannot be fully translocated to fruits as well as to roots, although one needs to be cautious regarding the species variation. For example, $eCO_2$ (950 μmol $mol^{-1}$) increased total soluble sugar in strawberry fruits by 20% relative to 350 μmol $mol^{-1}$ (Wang and Bunce, 2004). Similarly, the total soluble sugar was increased by 13% in radish and 20% in turnip under 1,000 μmol $mol^{-1}$ $CO_2$ compared to 400 μmol $mol^{-1}$ control (Azam *et al*., 2013) [3].

The leafy vegetables generally contain a greater concentration of nitrate, $eCO_2$ may promote N assimilation in leaves (Stitt and Krapp, 1999) [36]. For example, $eCO_2$ increased the N concentration in the inner leaves of lettuce cv. “Batavia Rubia Munguía” noninoculated with arbuscular mycorrhizal fungi to a greater extent than the outer leaves. Moreover, $eCO_2$ limits the uptake of nitrogen and the synthesis of nitrogenous compounds of vegetables to a lesser extent than that of other crops (mainly grain crops) (9.5% vs. 10-15%), probably because N deficiency is more common for grain crop cultivation in soils compared to vegetable cultivation.

Higher $CO_2$ results in greater photosynthetic rates initially but often photosynthetic acclimation, i.e., down regulation of net photosynthetic rates in the long term (Long *et al*., 2004; Kirschbaum, 2011) [26, 25], which indicates that increases in $CO_2$ concentration can substantially affect vegetable quality. Elevated $CO_2$ had increased the sucrose concentration of tomato fruits to a greater extent at the early fruiting stage than that at the later fruiting stage. The same pattern was noticed in terms of the concentrations of soluble sugars and organic acids in grapes. Plants grown in moderate vs. low light can generate more ATP and NADPH for carbon fixation, whereas high vs. moderate light may cause photoinhibition resulting from excessive light intensity that produces greater amounts of reactive oxygen species. Elevated $CO_2$ can improve vegetable quality under certain light intensities.

## Conclusion

At an elevated $CO_2$ concentration, the photosynthetic activity and translocation of photo assimilates are accelerated. In general, elevated $CO_2$ increases plant growth (both above- and belowground) and improve 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. $eCO_2$ can promote the accumulation of soluble sugar including glucose and fructose, and the accumulation of antioxidants including ascorbic acid, total phenols, and total flavonoids, but reduce the levels of protein, nitrate, Mg, Fe, and Zn in products. It is also important to determine the amount of C sequestered in soil from horticulture production practices not only for improvement of soil water-holding capacity, but also to aid in mitigation of projected global climate change. Furthermore, determining the contribution of the horticulture industry to these projected changes through flux of $CO_2$ and other trace gases (through irrigation and fertilization) is of critical importance. 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.

## References


1. Amthor JS, Loomis RS. Integrating knowledge of crop responses to elevated $CO_2$ and temperature with mechanistic simulation models: Model components and research needs. In: Koch, G.W. and H.A. Mooney (eds.). Carbon dioxide and terrestrial ecosystems. Academic Press, San Diego, CA; c1996. p. 317-346.
2. Arp WL. Effect of source-sink relations on photosynthetic acclimation to elevated CO. Plant Cell Environ. 1991;14:869-875.
3. Azam A, Khan I, Mahmood A, Hameed A. Yield, chemical composition and nutritional quality responses of carrot, radish and turnip to elevated atmospheric carbon dioxide. J Sci. Food Agric. 2013;93:3237-3244. DOI: 10.1002/jsfa.6165
4. Bowes G. Facing the inevitable: plants and increasing atmospheric CO. Annu. Rev. Plant Physiol., Plant Mol. Bio!. 1993;44:309-332.
5. Demmers-Derks H, Mitchell RAC, Mitchell VJ, Lawlor DW. Response of sugar beet (*Beta vulgaris* L.) yield and biochemical composition to elevated $CO_2$ and temperature at two nitrogen applications. Plant Cell Environ. 1998;21:829-836. DOI: 10.1046/j.1365-3040.1998.00327.x
6. Dong J, Xu Q, Gruda N, Chu W, Li X, Duan Z. Elevated and super-elevated $CO_2$ differ in their interactive effects with nitrogen availability on fruit yield and quality of cucumber. J Sci. Food Agric; c2018. DOI: 10.1002/jsfa.8976
7. Donnelly A, Lawson T, Craigon J, Black CR, Colls JJ, Landon G. Effects of elevated $CO_2$ and $O_3$ on tuber quality in potato (*Solanum tuberosum* L.). Agric. Ecosyst. Environ. 2001;87:273-285. DOI: 10.1016/S0167-8809(01)00144-X.
8. Fisher BU, Frehner UA, Hendrey GR, Blum H, Nosberger J. Source-sink relations in Lolium perenne L. as reflected by carbohydrate concentrations in leaves and pseudo-stems during regrowth in a free air carbon dioxide enrichment (FACE) experiment. Plant Cell Environ. 1997;20:945-952.
9. Fierro A, Gosselin A, Tremblay N. Supplemental carbon dioxide and light improved tomato and pepper seedling growth and yield. Hortscience. 1994;29:152-154.
10. Gruda N, Tanny J. Protected Crops, in Horticulture: Plants for People and Places: Production Horticulture, eds G. R. Dixon and D. E. Aldous (Dordrecht: Springer). 2014;1:327-405. DOI: 10.1007/978-94-017-8578-5_10
11. Gruda N, Tanny J. Protected Crops-Recent Advances, Innovative Technologies and Future Challenges. Leuven: International Society for Horticultural Science (ISHS); c2015. p. 271-278. DOI: 10.17660/ActaHortic.2015.1107.37
12. Gruda N. Impact of environmental factors on product quality of greenhouse vegetables for fresh consumption. Crit. Rev. Plant Sci. 2005;24:227-247. DOI: 10.1080/07352680591008628.
13. Heagle AS, Miller JE, Pursley WA. Growth and yield responses of potato to mixtures of carbon dioxide and ozone. J Environ. Qual. 2003;32:1603-1610. DOI: 10.2134/jeq2003.1603.
14. Houghton JT, Jenkins GJ, Ephraums JJ. Climate change: The IPCC scientific assessment. Cambridge University Press, Cambridge, UK; c1990.
15. Idso SB, Kimball BA. Downward regulation of photosynthesis and growth at high CO, levels. No evidence for either phenomenon in three-year study of sour orange trees. Plant Physiol. 1991;96:990-992.
16. Idso SB, Kimball BA. Effect of atmospheric CO, enrichment on photosynthesis, respiration, and growth of sour orange trees. Plant Physiol. 1992;99:341-343.
17. Idso SB, Kimball BA, Allen SG. CO, enrichment of sour orange trees: 2.5 years into a long-term experiment. Plant Cell Environ. 1991;14:351-353.
18. Ingvardsen C, Veierskov B. Response of young barley plants to CO, enrichment. J Exp. Bot. 1994;45:1373-1378

19. IPCC. Climate change 2007: The physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK; c2007.
20. Jin C, Du S, Wang Y, Condon J, Lin X, Zhang Y. Carbon dioxide enrichment by composting in greenhouses and its effect on vegetable production. J Plant Nutr. Soil Sci. 2009;172:418-424. DOI: 10.1002/jpln.200700220
21. Jain V, Pal M, Raj A, Khetarpal S. Photosynthesis and nutrient composition of spinach and fenugreek grown under elevated carbon dioxide concentration. Biol. Plant. 2007;51:L559-562. DOI: 10.1007/s10535-007-0122-9.
22. Kimball BA. Carbon dioxide and agricultural yield: an assemblage and analysis of 320 prior observations. A gran. J. 1983;75:779-788.
23. Keeling CD, Whorf TP. Atmospheric $CO_2$ records from sites in the SIO air sampling network, In: Trends: A compendium of data on global change. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Dept. Energy, Oak Ridge, TN; 2001. p. 14-21.
24. Kntecht GN, O'Leary lW. Increased tomato fruit development by CO, enrichment. J Am. Soc. Hortic. Sci. 1974;99:214-216.
25. Kirschbaum MU. Does enhanced photosynthesis enhance growth? Lessons learned from $CO_2$ enrichment studies. Plant Physiol. 2011;155:117-124. DOI: 10.1104/pp.110.166819.
26. Long SP, Ainsworth EA, Rogers A, Ort DR. Rising atmospheric carbon dioxide: plants FACE the Future. Annu. Rev. Plant Biol. 2004;55:591-628. DOI: 10.1146/annurev.arplant.55.031903.141610.
27. Makino A. Biochemistry of C3 -photosynthesis in high CO,. J Plant Res. 1994;107:79-84.
28. Masuda T, Fujita K, Ogata S. Effect of CO, enrichment and nitrate application on growth and dinitrogen fixation of wild and cultivated soybean plants during pod-filling stage. Soil Sci. Plant Nutr. 1989;35:405-416.
29. Moriguchi T, Abe K, Sanada T, Yamaki S. Levels and role of sucrose synthase, sucrosephosphate synthase, and acid invertase in sucrose accumulation in fruit of Asian pear. J Am. Soc. Hortic. Sci. 1992;117:274-278.
30. Moriguchi T, Sanada T, Yamaki S. Seasonal fluctuation of some enzymes relating to sucrose and sorbitol metabolism in peach fruit. J Am. Soc. Hortic. Sci. 1990;115:278-281.
31. Moretti CL, Mattos LM, Calbo AG, Sargent SA. Climate changes and potential impacts on postharvest quality of fruit and vegetable crops: a review. Food Res. Int. 2010;43:1824-1832. DOI: 10.1016/j.foodres.2009.10.013.
32. Neales TF, Nicholls AD. Growth responses of young wheat plants to a range of ambient $CO_2$ levels. Aust. J Plant Physiol. 1978;5:45-59
33. Neftel A, Moor E, Oeschger H, Stauffer B. Evidence from polar ice cores for the increase in atmospheric $CO_2$ in the past two centuries. Nature. 1985;315:45-47.
34. Ogata S, Fujita K, Matsumoto K. Effect of Al concentration in culture solution on the growth and N2 -fixation of some tropical pasture legumes. Soil Sci. Plant Nutr. 1986;32:27-35
35. Sage RF. Acclimation of photosynthesis to increasing atmospheric $CO_2$: The gas exchange perspective. Photosynth. Res. 1994;39:351-368.
36. Stitt M, Krapp A. The interaction between elevated carbon dioxide and nitrogen nutrition: the physiological and molecular background. Plant Cell Environ. 1999;22:583-621. DOI: 10.1046/j.1365-3040.1999.00386.x
37. Yamaki S, Moriguchi T. Seasonal fluctuation of sorbitol related enzymes and invertase activities accompanying maturation of Japanese pear (*Pyrus serotina* Rehder var. culta Rehder) fruit. J Jpn. Soc. Hortic. Sci. 1989;57:602-607.
38. Thompson L, Peffley E, Green C, Pare P, Tissue D. Biomass, flavonol levels and sensory characteristics of Allium cultivars grown hydroponically at ambient and elevated $CO_2$, in Proceedings of the 34th International Conferences on Environmental Systems (ICES), Colorado Springs, Colorado; c2004. DOI: 10.4271/2004-01-2300