Controlled environment agriculture (CEA) CARBON DIOXIDE INJECTION

Indoor production of leafy greens, **Part III:** Is carbon dioxide enrichment beneficial for indoor production of basil seedlings?

By Kellie J. Walters and Roberto G. Lopez

In this third article of a four-part series, researchers from Michigan State University share science-based information about indoor production of leafy greens and herbs. To read part one, visit **bit.ly/green-far-red-led-lighting**. *To read part two, visit* **bit.ly/green-blue-led-lighting**

Indoor vertical production of basil seedling under sole-source light-emitting diodes (LED)

PHOTO: ROBERTO G. LOPEZ

In recent years, researchers and growers have been mainly focused on quantifying the effects of sole-source light quality on crops grown in indoor CEA warehouses and containers. However, one commonly overlooked environmental parameter that has the potential to increase growth and yield is carbon dioxide (CO_2). Atmospheric (ambient) CO_2 concentration has been increasing over the years from below 320 µmol·mol^{-1} (or parts per million, ppm) in 1960 to current values where CO_2 levels outdoors comprise 0.04% of atmospheric volume, or around 400 µmol·mol^{-1}. However, CO_2 concentrations in a "tightly sealed" greenhouse or indoor growing operation can quickly dip down to 200 µmol·mol^{-1} as plants use CO_2 during photosynthesis. You may think that maintaining the CO_2 concentration at ambient levels is as easy as venting or introducing fresh air. It can be during certain times of the year, but this can be difficult when outdoor temperatures are very low. Increasing CO_2 to concentrations above ambient and up to 1,200 µmol·mol^{-1} has been shown to increase photosynthetic rates, growth and yield. There are several commercial methods to increase CO_2 concentrations above atmospheric levels. However, these methods should be deployed during periods when ventilation is minimal to reduce the loss of the added CO_2 outside of the growing area.

For CO_2 enrichment above ambient, growers can deploy CO_2 burners that produce CO_2. This method produces some heat, moisture and CO_2 by burning natural gas or propane. Incomplete combustion or contaminated fuels can lead to the introduction of toxic gases for both plants and humans. To improve CO_2 uniformity, burners should be dispersed throughout and horizontal air flow (HAF) fans can be deployed to circulate air. Another method of CO_2 enrichment for both greenhouses and indoor farms is injecting compressed or liquid CO_2 from a tank. The compressed CO_2 is converted from a liquid to a gas and then released into the growing area. These tanks can be rented or purchased through local gas distributors. When delivered in this form, CO_2 is often dispersed through polyethylene tubes. Remember that CO_2 is heavier than the other air components, so concentrations tend to be greater closer to the floor.

Experimental protocol

The goal of our research program is to develop indoor and greenhouse environmental management protocols for different stages of culinary herb production. Given that CEA production is energy-intensive, we have focused our efforts on young plant production since inputs such as light and CO_2 can be delivered across more plants at the seedling stage when plant density is greater compared to the finished stage when plant density is lower. The objectives of our research were to determine if indoor CO_2 enrichment during the seedling stage influences: 1) sweet basil seedling growth and development; 2) morphology, growth, and yield at harvest in the greenhouse; and 3) volatile oil content and flavor (this research is in progress and we will report the results in an upcoming article).

Sweet basil 'Nufar' seeds were sown in Grodan rock-wool cubes and placed in walk-in growth chambers with an average

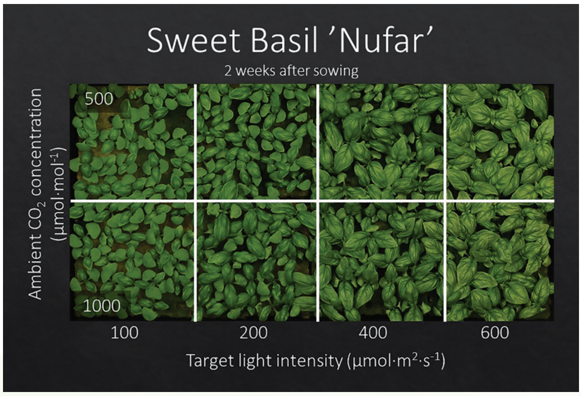

Fig. 1. Sweet Basil 'Nufar' grown in growth chambers with either 500 or 1,000 µmol·mol^{-1} CO_2 and light intensities of 100, 200, 400 or 600 µmol·m^{-2}·s^{-1} two weeks after sowing.

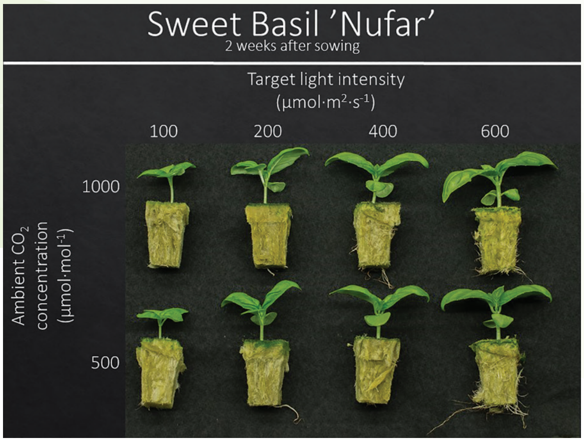

Fig 2. Sweet Basil 'Nufar' grown in growth chambers with either 500 or 1,000 µmol·mol^{-1} and light intensities of 100, 200, 400 or 600 µmol·m^{-2}·s^{-1} two weeks after sowing.

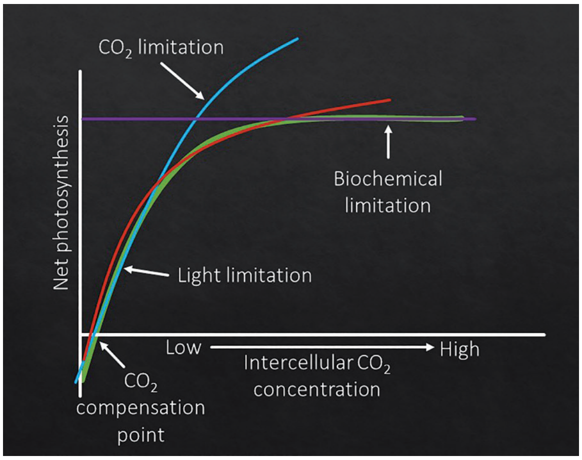

Fig. 3. Limitations to photosynthesis include carbon dioxide (CO_2; blue line), light intensity (red line) and biochemical (phosphate; purple line). The green line represents a theoretical photosynthetic response curve.

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Cross-merchandising of fresh-cut basil and tomatoes

PHOTO: KELLIE WALTERS

daily temperature (ADT) set point of 73° F (23° C) and CO_2 set points of 500 or 1,000 µmol·mol^{-1} throughout the day and night. We maintained these concentrations by injecting compressed CO_2 into the chambers, and by scrubbing CO_2 with soda lime when concentrations were too high. In each chamber we had four light intensity treatments of 100, 200, 400 and 600 µmol·m^{-2}·s^{-1} that operated 16 h per day to create daily light integrals (DLIs) of 6, 12, 23 or 35 mol·m^{-2}·d^{-1}. This allowed us to determine whether there was an interaction between CO_2 concentration and light intensity. The seedlings were grown for two weeks, after which plants were transplanted into deep flow technique (DFT) hydroponic systems in a greenhouse with an ADT of 73° F (23° C) and a DLI of 14 mol·m^{-2}·d^{-1}. With the plants growing in a common greenhouse environment, we could evaluate if differences or higher inputs at the seedling stage would result in increased yields down the road.

In theory, by increasing CO_2 concentration, we should have seen increased growth; however, this was not the case. As can be seen in **Figs. 1 and 2**, light intensity had a much larger impact on seedling growth than CO_2, but we will discuss that in the next article of this series. Increasing CO_2 concentration did not influence growth and development. Why would increasing CO_2 from 500 to 1,000 µmol·mol^{-1} not actually improve growth and development of basil seedlings?

There are three main limitations to photosynthesis: the supply or utilization of CO_2, of light, or of phosphate (also referred to as biochemical limitation; **Fig 3.**). Theoretically, if CO_2 concentration starts at 0 and increases, you will hit a CO_2 compensation point above which plants have positive net photosynthesis. As the CO_2 concentration further increases, the photosynthetic rate will increase until the CO_2 concentration reaches a species or cultivar-dependent saturation point. In our case, 500 µmol·mol^{-1} CO_2 may have been near the saturation point for basil seedlings. Therefore, increasing the concentration to 1,000 µmol·mol^{-1} did not significantly increase growth. In addition, if photosynthesis is light-limited, increasing CO_2 concentration will not result in large increases in photosynthesis. Conversely, if photosynthesis is CO_2-limited, increasing light intensity will not result in large increases in photosynthesis. However, increasing CO_2 can have some other positive effects, including reducing oxygenation and photorespiration. In our case, increasing the light intensity further or growing the plants past the transplant stage may have resulted in differences between CO_2 treatments.

Do our results mean we should write off CO_2 enrichment as a means of increasing photosynthesis and ultimately growth and yield? No. We are currently evaluating several other culinary herbs at lower and higher CO_2 concentrations and a range of light intensities to see if there is a species-dependent response. In addition, it is possible that elevating CO_2 concentration would have a larger impact during the finish stage. More studies are needed to parse out which horticultural crops and at what stage of production CO_2 enrichment would be the most beneficial to improving growth and yield.

Take-home message

Other environmental factors besides CO_2 concentration may have a larger impact during the seedling stage. Read the last article in this four-part series to understand the benefits of increasing indoor CEA light intensity during propagation on subsequent yield in the greenhouse. **pg**

Kellie is a PhD student and Roberto is assistant professor and controlled environment/floriculture extension specialist in the Department of Horticulture at Michigan State University. The authors gratefully acknowledge Sean Tarr and Nate DuRussel for assistance, Fluence Bioengineering for LEDs, JR Peters for fertilizer, Grodan for substrate, Hydrofarm for hydroponic production systems, Dramm for irrigation equipment and MSU AgBioResearch, MSU Graduate School and the USDA-NIFA for funding.