# Balancing for Success:

## Optimizing $CO_2$, Light, and Temperature

(answers from David Imberti, mathematical modeler and software developer at Percival Scientific, who shared his insights during a panel discussion at Indoor Ag-Con 2024)

## Indoor Ag-Con Panel Discussion Questions

**Q:** What methods can be employed to study the effects of simultaneous manipulation of $CO_2$, light, and temperature on plant health, stress response and resistance to pathogens? In other words, given the system's complexity, how can one design a controlled experiment to understand the impacts of changes in these variables?

**A:** Tight control over the environmental parameters and very high levels of uniformity across the study area are essential and fundamental aspects of replicable plant science experiments. These requirements should be tested and confirmed before beginning any study. The consensus is to follow "Experimental Control 101," which means keeping excellent stats and understanding the differences between experimental, sampling, and replication biases. This need for replicability is why a specially designed growth chamber is required for reliable results.

**Q:** The interaction between light, $CO_2$, and temperature suggests balancing these factors is complex. What strategies do you recommend for managing this complexity?

**A:** There are machine learning algorithms specialized for this purpose. Ultimately, a system with a large dataset and deep learning to create bespoke parameters is hard to beat—provided it has been tried and tested in the field and is not just based on a computer scientist's theory.

However, if you need something more basic and straightforward, try keeping different controls on different timescales. For example, humidity control will often fight against temperature control (refrigeration-based dehumidification will cause a significant cool-down, and many humidification systems will introduce an additional heat load), so setting humidification systems to act on a slower timescale than temperature control and temperature uniformity systems is one possible approach.

It's important to keep a holistic view of the different system responses. For example, plants need a lot more $CO_2$ as the lighting ramps up. Lighting will impact temperature offsets used in the temperature control, and so on. Again, complex systems can be used to deal with this, but if you need something more practical, maintaining good calibration, simple offsets, and stepping through all the nested case logic for these systems is another strategy.

## General Questions About $CO_2$, Light, and Temperature

**Q:** What is an optimal light level to use for plant growth?

**A:** Consult a plant information table (Plant Growth Chamber Handbook published by NCERA-101 is a good source, among many others), as optimal light levels can vary significantly depending on the plant variety and stage. For instance, the photoperiod could be the longest during the flowering stage and shortest during the propagation stage.

**Q:** What's the best kind of light to use for plant growth?

**A:** As a general guide, try to match the plant environment, time of day, and seasonal period. In other words, mimic what the sun would do in that plant's original environment. Red treatments at the beginning and end of the day are recommended. For flowering in most plants, you can use a red and far-red combination treatment at the end of the season. If you have no idea where to start, try beginning with 20% blue, 53% red, and 27% far-red. Then adjust the percentages according to the plant response. Almost every color range can have a very specific plant response, depending on your need.

**Q:** What's a recommended temperature range for plant growth?

**A:** Again, a plant information table can give you the best range for a particular plant species. Some want the same temperature, and others do better with a temperature range that correlates with light and darkness (a diurnal period). Most plants do well around 20-25°C.

That said, it's also important to consider vapor pressure deficit (vpd) levels, as both the temperature and the %RH must be managed to hit ~1kPa vpd for most plants. You should also be aware that temperature can vary widely throughout the growth space: high-intensity, non-uniform lighting can cause significant temperature offsets.

**Q:** What's a recommended airspeed for plant growth?

**A**: It's important to note that airspeeds must be limited to below 0.7 m/s across the plants, as speeds above this can cause damage. Many growers, in their drive to maximize uniformity to optimize plant quality, will use large amounts of airflow and destroy their crop. So, you need to be aware of the difference between the volumetric and linear airflows in your space.

**Q:** What's the recommended level of $CO_2$ to use?

**A:** There's often a diminishing return above 1,000 ppm. Most of the time, you don't want to exceed 2,000 ppm or 0.2%. Ambient is 400 ppm; you generally don't want to go below that. In many cases, 150 ppm is used for plant-life sterilization.

$CO_2$ levels can vary quite a bit in large growing spaces, depending on the type of plants and how much they are absorbing (maize and cotton are much more efficient at scrubbing the $CO_2$ levels, for example), so levels should be monitored. Also, keep in mind that soil bacteria can raise $CO_2$ levels quite a bit at night. The potential risks of not maintaining optimal $CO_2$ levels are significant, so it's crucial to monitor and control them.