Carbon Dioxide Enrichment

NGMA Helpful Hints

CO2 Concentration and Plants

Photosynthesis is the process of plants using light energy to convert absorbed carbon dioxide (CO2) and water into sugars. Plants use these sugars for growth through the process of respiration.

Plants absorb CO2 through their stomatal openings located mainly on the underside of leaves. Although light, moisture, temperature and humidity levels all affect the rate of CO2 absorption, the concentration of CO2 outside the leaves is a significant influence.

The concentration of CO2 in ambient outside air commonly varies from 300 to 500 parts per million (ppm) or more by volume depending on the season, time of day and the proximity of CO2 producers such as combustion or composting, or CO2 absorbers such as plants or bodies of water. Plants growing in greenhouses, particularly "tight" double-layer structures with a reduced air infiltration rate, can reduce CO2 levels to well below ambient levels, greatly reducing the rate of photosynthesis. Conversely, enriching the concentration of CO2 above ambient levels will significantly increase the rate of photosynthesis. In general, a drop in CO2 levels below ambient has a stronger negative effect on plant growth than the positive effects of enriching CO2 levels above ambient.

Daily CO2 levels in un-enriched greenhouse environments will climb to several hundred ppm above outdoor ambient at night due to CO2 produced by plant and microbial respiration. CO2 levels drop quite rapidly after sunrise as the crop's photosynthetically-driven consumption of CO2 exceeds the basic rate of respiration. In the absence of some other source, CO2 levels remain low all day limiting plant growth. At dusk, plant and microbial respiration once again begins to accumulate CO2 in the greenhouse.

CO2 is added in some greenhouses to increase growth and enhance crop yields. The ideal concentration depends on the crop, light intensity, temperature and the stage of crop growth. This document is intended to provide the basics of CO2 enrichment so growers, in conjunction with industry experts, can research the best options for their particular greenhouse operations.

How is CO2 concentration monitored?

Most growers do not monitor CO2 levels in the greenhouse because they have no intention of controlling it. As long as their crops are growing and developing to their satisfaction, this is a reasonable approach.

CO2 levels in the greenhouse may be monitored using relatively low-cost dual beam infrared CO2 gas monitors. These monitors may be linked to climate control systems that integrate other factors such as indoor & outdoor air temperature, humidity & light intensity. More expensive monitors with higher accuracies are available, but in most applications reliability and economical cost are the most important factors.

Although basic CO2 dosing may be applied without monitoring CO2 levels, the relatively low cost of a good CO2 metering system pays for itself in the form of cost savings from supplemental CO2 sources.

When is CO2 enrichment needed?

CO2 enrichment is not required as long as the crops are growing and developing to the complete satisfaction of the grower, or if high ventilation rates make CO2 enrichment uneconomical. CO2 enrichment should be considered, however, if crop production and quality are below required levels.

In general, crop production times from late fall through early spring increases the potential need for CO2 enrichment as it coincides with reduced ventilation rates due to colder outdoor air temperatures. As ventilation rates are increased for cooling and dehumidification from late spring to early fall, the cost of CO2 enrichment escalates while the benefit to the crop may be minimal or reduced.

As photosynthesis and CO2 consumption happens only during daylight hours, CO2 enrichment at night is not required. In general, CO2 enrichment systems should be turned on 1 or 2 hours after sunrise, and turned off several hours before sunset, however, additional CO2 enrichment may be needed if supplemental grow-lighting is used.

How are CO2 levels enriched?

1. Maximize Natural (Free) CO2 Supply: Maximize ventilation rates whenever possible starting 1 or 2 hours after sunrise when the overnight build-up of CO2 has been depleted. Improve horizontal air flow to distribute available CO2 evenly throughout the crop and to reduce the leaf boundary layer, which will improve the diffusion of CO2 into the stomatal openings of each leaf. Keep plants healthy and well-watered so they are not forced to close their stomatal openings due to stress. Depending on the crop, consider using natural sources of CO2 such as decomposing straw bales and/or organic soil mixes in your production system.

2. Liquid or Bottled CO2 Gas: When outside air conditions are too extreme for ventilation, additional CO2 is available in the form of liquid or bottled CO2 gas. Specific processes are required for the safe & proper handling as well as the effective use of CO2 from these sources. Liquid CO2 must be fully vaporized before delivering into the greenhouse, and manufacturers' instructions and local codes should be strictly adhered to.

3. CO2 from Carbon-Based Fuels: Gas-fired appliances generate CO2 and water vapor as primary byproducts of combustion. These appliances include equipment that is specifically designed & certified as CO2 generating appliances, un-vented forced-air primary space heaters, and hot water boiler heating systems with flue gas condensers specifically designed for CO2 enrichment.

Achieving complete combustion is the key to success of CO2 enrichment through appliances burning natural or propane gas. Incomplete combustion may occur due to relatively common factors such as improper or fluctuating gas pressure, impurities in the gas supply, inadequate oxygen for combustion, wind disturbance in the burner and clogged gas orifices. Harmful byproducts of incomplete combustion include Nitrogen Oxides, Carbon Monoxide and Ethylene.

To increase the likelihood of complete combustion, it is recommended to use only gas-fired appliances that are certified by 3rd-party testing agencies (CSA, ETL, UL, etc.) to meet nationally recognized safety standards. Agency-certified appliances should only be used for the applications that they are certified for, and the appliances should include installation, operating & maintenance instructions with the product. These instructions should be strictly adhered to and saved in a convenient place.

As water vapor is also a primary byproduct of combustion, un-vented gas appliances have the potential to create difficulties in the naturally humid greenhouse environment. Condensation due to high humidity promotes many plant diseases. Condensation from combustion is also slightly acidic, which may prematurely corrode metal structures, equipment and wiring on contact.

Building codes and manufacturers of un-vented gas appliances typically require minimum rates of air changes in the greenhouse per volume of fuel burned. Although introducing fresh outside air will increase greenhouse heating costs in colder weather, these ventilation rates are necessary to ensure adequate supplies of oxygen for complete combustion, and to prevent the build-up of unwanted water vapor and/or contaminants due to incomplete combustion.

NGMA Helpful Hints

Is CO_2 enrichment safe?

CO_2 is harmless to humans at all reasonable dosing levels, and OSHA has established workplace standards for worker exposure. While humans can work safely at these elevated CO_2 levels, many crops start to show undesirable growth responses at CO_2 concentrations above 1,200 to 2,000 ppm.

For gas-fired CO_2 generators, adequate ventilation air should be introduced to provide enough oxygen for complete combustion, and to limit the build-up of water vapor and other potential contaminants in the greenhouse.

General Tips & Conclusion

CO_2 enrichment can be a useful tool for maximizing the quantity and quality of your greenhouse product. Healthier crops and higher yields helps to satisfy customers, command higher prices and reduce costs, all of which makes a greenhouse operation more competitive. The decision to proceed with CO_2 enrichment should follow a thorough cost/benefit analysis, and success depends on each grower developing a strategy based on their unique combination of greenhouse structure, crop type, local weather, stage of production and capital/operating budgets. Once a CO_2 enrichment strategy is selected, always follow the instructions and installation & service manuals of equipment and/or chemical manufacturers. Make sure national and local codes covering greenhouse operations are adhered to, and use qualified & experienced service agencies and technicians for installing and maintaining CO_2 enrichment systems.

Reviewing these Helpful Hints and gathering more information from available horticultural industry experts and resources will help you make informed decisions, and enhance any CO_2 enrichment strategy's effectiveness.

For more information, please contact:
National Greenhouse Manufacturers Association
717-238-4530 or info@ngma.com