CO_2 Consumption in Greenhouses:

Carbon Dioxide (CO_2)

Photosynthesis is the process which involves a chemical reaction between water and carbon dioxide in the presence of light, to make food (sugars) for plants and as a byproduct releases oxygen in the atmosphere. Carbon dioxide currently comprises .04% (400 ppm) of the atmospheric volume. It is a colorless and odorless minor gas in the atmosphere, but has an important role for sustaining life. Plants take in CO_2 through small cellular pores called stomata in the leaves during the day. During respiration (oxidation of stored sugars in plants producing energy and CO_2) plants take in oxygen (O_2) and give off CO_2 , which complements photosynthesis when plants take in CO_2 and give off O_2 . The CO_2 produced during respiration is always less than the amount of CO_2 taken in during photosynthesis. So, plants are always in a CO_2 deficient condition, which limits their potential growth.

CO_2 Concentration in Relation to Plants Photosynthesis utilizes CO_2 in the production of sugar which degrades during respiration and helps in plant's growth. Although atmospheric and environmental conditions like light, water, nutrition, humidity and temperature may affect rate of CO_2 utilization, the amount of CO_2 in the atmosphere has a greater influence. Variation in CO_2 concentration depends upon the time of day, season, number of CO_2 -producing industries, composting, combustion and number of CO_2 -absorbing sources like plants and water bodies nearby. The ambient CO_2 (naturally occurring level of CO_2) concentration of 400 ppm can occur in a properly vented greenhouse. However, the concentration is much lower than ambient during the day and much higher at night in sealed greenhouses. Carbon dioxide level is higher at night because of plant respiration and microbial activities. Carbon dioxide level may drop to 150-200 ppm during the day in a sealed greenhouse because CO2 is utilized by plants for photosynthesis during daytime. Exposure of plants to lower levels of CO2 even for a short period can reduce rate of photosynthesis and plant growth. Generally, doubling ambient CO2 level (i.e. 700-800 ppm) can make a significant and visible difference in plant yield. Plants with a C3 photosynthetic pathway (geranium, petunia, pansy, aster, lily and most dicot species) have a 3-carbon compound as the first product in their photosynthetic pathway, thus are called C3 plants and are more responsive to higher CO2 concentration than plants having a C4 pathway (most of the grass species have a 4-carbon compound as the first product in their photosynthetic pathway, thus are called C4 plants). An increase in ambient CO2 to 800-1,000 ppm can increase yield of C3 plants up to 40%–100% and C4 plants by 10%–25% while keeping other inputs at an optimum level. Plants show a positive response up to 700-1,800 ppm, but higher levels of CO2 may cause plant damage.

CO2 Supplementation In general, CO2 supplementation is the process of adding additional CO2 in the greenhouse, which increases photosynthesis in a plant. Although benefits of high CO2 concentration have been recognized since the early 19th century, growth of the greenhouse industry and indoor gardening since the 1970s has dramatically increased the need for supplemental CO2 . The greenhouse industry has advanced with new technologies and automation. With the development of improved lighting systems, environmental controls and balanced nutrients, the amount of CO2 is the only limiting factor for maximum growth of plants. Thus, keeping the other growing conditions ideal, supplemental CO2 can provide improved plant growth. This is also called CO2 enrichment' or 'CO2 fertilization.

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Advantages

- Increase in photosynthesis results in increased growth rates and biomass production.
- Plants have earlier maturity and more crops can be havested annually. The decrease in time to maturity can help in saving heat and fertilization costs.
- In flower production, supplemental CO2 increases the number and size of flowers, which increase the sales value because of higher product quality.
- Supplemental CO2 provides additional heat (depending upon the method of supplementation) through burners, which will reduce heating cost in winter.
- It helps to reduce transpiration and increases water use efficiency, resulting in reduced water use during crop production.

Disadvantages

- Higher production cost with a CO2 generation system.
- Plants may not show a positive response to supplemental
- CO2 because of other limiting factors such as nutrients, water and light. So, all factors need to be at optimum levels.
- Supplementation is more beneficial in younger plants.
- Incomplete combustion generates harmful gases like sulphur dioxide, ethylene, carbon monoxide and nitrous oxides. These gases are responsible for necrosis, flower malformation and senescence if left unchecked, resulting in lower quality products.
- Additional costs required for greenhouse modification. Greenhouses need to be properly sealed to maintain a desirable level of CO2.
- Excess CO2 level can be toxic to plants as well as humans.
- On warmer days it is difficult to maintain desirable higher

CO2 levels because of venting to cool the greenhouses.

Effect of supplemental CO2 on different growing factors

CO2-light

The rate of photosynthesis cannot be increased further after certain intensity of light termed as the light saturation point, which is the maximum amount of light a plant can use. However, additional CO_2 increases the light intensity required to obtain the light saturation point, thus increasing the rate of photosynthesis. Mostly in the winter, photosynthesis is limited by low light intensity, and an additional lighting system will enhance the efficiency of CO_2 and increase the rate of photosynthesis and plant growth. Thus, supplemental CO_2 integrated with supplemental lighting can decrease the number of days required for crop production.

CO2-water:

Supplemental CO_2 affects the physiology of plants through stomatal regulation. Elevated CO_2 promotes the partial clo- sure of stomatal cells and reduces stomatal conductance.

Stomatal conductance refers to the rate of CO_2 entering and exiting with water vapor from the stomatal cell of a leaf. Because of reduced stomatal conductance, transpiration (loss of water from leaf stomata in the form of water vapor) is minimized and results in an increased water use efficiency (WUE) (ratio of water used in plant metabolism to water lost through transpiration). Lower stomatal conductance, reduced transpiration, increased photosynthesis and an increase in WUE helps plants to perform more efficiently in water-stressed conditions. Supplemental CO_2 reduces water demand and conserves water in water-scarce conditions.

CO2 -temperature

Temperature plays a big role in the rate of plant growth.

Most biological processes increase with increasing tempera- ture, this includes the rate of photosynthesis. But the optimum temperature for maximum photosynthesis depends on the availability of CO_2. The higher the amount of available CO_2, the higher the optimum temperature requirement of crops (Fig 2). In a greenhouse supplemented with CO_2, a dramatic increase in the growth of plants can be observed with increas- ing temperature. Supplemental CO_2 increases the optimum temperature requirement of a crop. This increases produc- tion even at higher temperature, which is not possible at the ambient CO_2 level.

CO2 -nutrient

A major effect of CO_2 supplementation is the rapid growth of plants because of enhanced root and shoot growth. The enhanced root system allows greater uptake of nutrients from the soil. It is recommended to increase fertilizer rate with increasing CO_2 level. The normal fertilizer rate can be exhausted quickly and plants may show several nutrient deficiency symptoms.

Control and Distribution of CO_2

Depending on the size of the greenhouse and type of system installed, the CO_2 level in the greenhouse is controlled manually or through a computer-based system. A CO_2 gas sensor (Fig. 5) gives the level of CO_2 concentration in the greenhouse atmosphere and a generator is manually turned on and off based on the readings of the sensor. The sensor measures temperature and humidity along with CO_2 and helps in developing a crop management strategy. However, in the case of the computer-based system, sensors signal the current CO_2 level to the control system and a control system turns on and off the generator based on the set points created by the grower.

CO_2 diffuses slowly, so proper air circulation is essential to distribute CO_2 evenly. Generally, a small greenhouse with a single CO_2 generator uses fan jets or horizontal air flow fan for distribution. However, a large connected greenhouse with a flue gas generator generally uses plastic tubes underneath the bench (right below the crop level) and are perforated at different intervals to diffuse CO_2. The main advantage of such tubing is to supply adequate CO_2 to the boundary layer of a leaf even in dense canopy conditions.