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# Safe and Effective CO2 Enrichment in the Garden

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CO2 enrichment in the garden often makes all the difference between a satisfying harvest and an exceptional one! When plants are provided with a CO2 concentration between 700 and 1,000 parts per million (ppm), they can achieve optimal photosynthesis resulting in record growth! Knowing that the outdoor air contains an average CO2 concentration of approximately 400 ppm, we clearly understand the benefits of CO2 enrichment. But which enrichment method is best to choose? How can we ensure the well -being of our plants and our safety? This article will answer these questions and more!

## Choosing the appropriate CO2 enrichment method for your garden

The best known and most effective methods of CO2 enrichment are combustion CO2 generators and CO2 bottle regulators. Other methods of CO2 enrichment include a baking soda and vinegar mix, compost, dry ice or fermentation, but these methods are less effective and can be difficult to control.

| | Combustion Generator | $CO_2$ Bottle and Regulator |
|---|---|---|
| Price | • Operating costs are relatively low once the $CO_2$ generator is purchased.<br>• More economical than $CO_2$ bottles. | • Expensive source of $CO_2$.<br>• The larger your garden, the higher the cost. |
| Impacts on the garden's climate | • Produces heat and water vapor: one pound of propane generates about 1.5 pounds of water and 20,000 BTU of heat.<br>• $CO_2$ generators are not recommended for small growing volumes (less than 424 cubic feet).<br>• Requires good management of temperature and humidity to avoid damage to plants. | • The garden's climate is not affected since no heat or water vapor is generated.<br>• Can be used in the presence of high temperature and humidity levels in the garden.<br>• Excellent choice for small growing volumes. |
| Potential Toxicity | • Risk of toxicity in cases of incomplete combustion caused by defective device or lack of oxygen.<br>• Poor quality of fuels are to be avoided: some may cause sulfur dioxide pollution (e.g. kerosene). | • Safe source of $CO_2$.<br>• Risk free for crops, since no toxic gas is released. |
| Others | • A generator with a heat exchanger can recover some of the heat generated by combustion to heat another room. | • Regulators may freeze at large gas flow (more than 20 cubic feet per hour).<br>• Some models can withstand gas flow up to 50 cubic feet per hour without freezing. |

A comparison between Combustion Generators and a CO2 Bottle and Regulator.

## Combustion generator or CO2 bottle?

As its name indicates, the generator creates CO2 by combustion. The most common fuels used are propane and natural gas. When there is sufficient oxygen available for complete combustion, the generator converts more than 99 per cent of the gas into CO2 and water vapor. As for the pressured liquid CO2 bottle, the operation is simple: with a proper regulator, the CO2 is gradually released from the bottle into the garden. The following table shows the pros and cons of using these two methods according to price, influence on the climate and toxicity.

## CO2 and Safety: Potential risks related to a high CO2 concentration

A CO2 concentration equal or greater than 1,500 ppm may cause partial or complete closure of the plant's stomas which results in a reduction of CO2 absorption as well as a limitation in plant transpiration. Transpiration is an essential process to plant growth since the roots absorption of water and nutrients depends on it. Far from serving the plants best interests, an excess of CO2 will slow down growth.

For gardeners, an excess of CO2 is just as harmful, if not more so! The maximum CO2 concentration exposure is a 15 minutes period at about 30,000 ppm , but possible side effects can occur at a concentration as low as 1,000 ppm. High concentrations may occur with defective equipment (generator, CO2 bottle, regulator, controller), and especially in confined and isolated spaces with poor air exchange. Above 10,000 ppm, the side effects on human health worsen as the CO2 concentration and duration of exposure increase.

To prevent excessive CO2 concentrations, regular inspection and maintenance of the enrichment equipment used in the garden is important. For CO2 bottles, it is possible to spray the equipment fittings with soapy water; if there is a leak, bubbles will appear where the gas is escaping. Getting a CO2 monitoring device is also strongly recommended; knowing the ambient CO2 concentration allows fast reactions in case of danger. A CO2 controller is a very interesting solution. Not only will it ensure safety, it will also maintain a stable and precise concentration in the garden (great benefit to plants) and the gardener will benefit from great savings!

## The dangers of incomplete combustion

In the particular case of a combustion generator, there is an additional risk: an incomplete combustion caused by a defective burner or a lack of oxygen. When properly burned, propane and natural gas produce bright blue flames dotted with purple flames

| $CO_2$ Concentration (ppm) | Side effects on health* |
|---|---|
| ~ 400 | None (normal concentration in outdoor air) |
| ~ 600-800 | None (normal concentration in well ventilated houses and offices) |
| ~ 1,000 | May cause asthma or sick building syndrome<br>May cause drowsiness if exposure is prolonged |
| ~ 5,000 | Professional limit exposure in many countries (for eight hours) |
| ~ 10,000 | Drowsiness if exposure is prolonged |
| ~ 20,000 | Increase of respitary amplitude |
| ~ 30,000 | Respiratory rate two times higher than normal<br>Exposure limit: 15 minutes |
| ~ 40,000 | Limit for irreversible effects on health |
| ~ 50,000 | Dizziness, confusion, respiratory difficulties, headaches<br>Respiratory rate four times higher than normal |
| ~ 100,000 | Visual disorder, shaking, sweating<br>More than 10 minutes exposure can lead to death |
| ~ 150,000 | Sudden loss of conciousness |
| ~ 250,000 | Respiratory arrest resulting in death |

Health side effects of exposure to different CO2 concentrations.

(figure one). The combustion is odorless and clean, producing CO2 and water vapor. Incomplete combustion is easy to detect with its often flickering orange and yellow flames. It creates a danger from the toxic compounds that emerge from the flames, which are harmful to plants and humans and can even be fatal. The main toxic gases from incomplete combustion are carbon monoxide (CO), ethylene (C2H4), sulfur dioxide (SO2), nitrogen monoxide and nitrogen dioxide (NO and NO2) and propylene (C3H6). Their effects on plants and humans are numerous, but here are the main ones.

Carbon monoxide is a colorless, odorless, tasteless and non irritating gas. However, it is very toxic! Exposure to low doses may cause flu symptoms on humans, but higher doses are dangerous and can be fatal. Poisoning occurs when inhaled carbon monoxide replaces the oxygen in the blood. As the carbon monoxide level increases in blood, the oxygen level decreases and the body's organs and tissues may no longer function properly. The main systems affected are the cardiovascular and nervous systems.

*"The results from a garden that benefits from good CO2 enrichment management will be worth the invested time and money."*

Ethylene is a gas that is naturally produced from the plants and can have various effects. Mainly, it causes fruit ripening, aging of the organs and may also cause the leaves to fall. Without getting into these complex processes, the presence of ethylene at the wrong stage of development may have side effects on plants such as preventing flowering, reducing the yield and fruit quality or causing the leaves to lose chlorophyll, a reduction of flower's pigmentation and other wilting symptoms. At high concentrations, propylene may cause similar symptoms to carbon monoxide.

Sulfur dioxide is also harmful to plants. When this gas is present in abundant quantities, the plants close their stomas. As for nitrogen oxides, a large quantity may decrease the plant's growth and cause necrosis. Interestingly, a low concentration combination of sulfur dioxide and nitrogen oxide may be more damaging to plants than a high concentration of one of these two gases.

| Gas | Critical Concentrations (ppm) | |
|---|---|---|
| | Plants | Human |
| Ethylene ($C_2H_4$) | 0.01 to 0.5 | 5 |
| Sulfur Dioxide ($SO_2$) | 0.1 to 0.5 | 2 |
| Nitrogen monoxide and dioxide (NO and $NO_2$) | 0.01 to 0.5 | 25 to 30 |
| Propylene ($C_3H_6$) | 10 to 50 | - |
| Carbon Monoxide (CO) | 100 to 500 | 50 |
| Carbon Dioxide ($CO_2$) | 2,000 to 30,000 | 5,000 |

Illustrating the critical concentration of gases affecting humans and plants.

## Critical concentrations of gases emitted by incomplete combustion

With that said, how can we protect ourselves against the side effects of incomplete combustion? First, proper maintenance and verification of the generator should be frequently executed. Then, the room where the generator is being used should contain enough oxygen to allow complete combustion. A simple way to do it is to make sure some ventilation is present with the outdoor air to maintain an acceptable oxygen level without wasting the precious generated CO2. For example, a 24,000 BTU CO2 generator requires about five cubic feet (CF) of air per minute of functioning. So if a generator burns for 15 minutes per hour, it requires five by 15 = 75 CF per hour of fresh air. Thus, a 100 CFM fan has to work about one minute per hour to replenish the oxygen supply to ensure complete combustion.
Another strongly recommended protection is to purchase a detector. Some gases, such as ethylene, strongly affect plants but are expensive to detect. However, it is not expensive to acquire a carbon monoxide monitor, and it is a good indicator of combustion quality. Normally, a concentration greater than 30 ppm of carbon monoxide in the undiluted gas from the generator indicates incomplete combustion; the presence of other harmful gases is very likely.

In order to avoid wasting CO2, some gardeners choose a culture volume as airtight as possible, without any air exchange. The CO2 generator is not recommended in this type of confined space due to a high risk of lack of oxygen and, therefore, incomplete combustion. The CO2 bottle is much safer for this type of garden.

Selecting and applying an appropriate CO2 enrichment method for the growing area is no easy task. But taking the time to do so will allow one to achieve the expected results and will ensure the plants' and the gardener's safety. The results from a garden that benefits from good CO2 enrichment management will be worth the invested time and money.