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Carbon Dioxide in the Greenhouse Atomosphere

By

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Most of the applied research on greenhouse crops during the past fifteen years has dealt with effects of various environmental factors on plant growth. When plants are grown in greenhouses, factors such as water, light, temperature, and nutrients are more easily controlled and supplied for optimum growth. Carbon dioxide, a very essential factor in the plant's environment, has had little investigation within the greenhouse.

During the past year controlled facilities for carbon dioxide research were constructed at Colorado State University. A Beckman infra-red gas analyzer was also obtained for sampling, analyzing and recording CO_2 concentrations from various locations throughout the research greenhouses. We now have one year of continuous records indicating the carbon dioxide level in several greenhouses and are able to determine the various conditions when carbon dioxide becomes limiting to plant growth. This is the first of a series of progress reports on this research.

Carbon dioxide is extremely important both to total growth and to quality. Plants are able to combine carbon dioxide and water with the aid of light energy to form sugars. This process, called photosynthesis, is a basic process in nature and has not been achieved without the aid of living plants. Carbon dioxide, which is present in varying amounts around a plant, diffuses through the stomates into the leaves and dissolves in the water on the cell walls. The CO_2 is then moved inside the cells where sugars are formed. These sugars may be built into more complex starches and proteins or may be stored as reserve food for later use by the plant. As these complex compounds are formed they tend to increase the dry matter in the plant, which leads to an increase in quality and quantity of flowers or plant material produced.

Another process that takes place in plants is called respiration. In order to obtain energy for growth, sugars and other foods are broken down to water and carbon dioxide. Respiration is taking place in plants at all times, but its reverse process, photosynthesis, predominates during light periods. During the night, a plant releases CO_2 which actually builds up in the greenhouse. During the day a plant uses much more CO_2 than it releases, hence carbon dioxide may limit growth unless the supply is renewed.

Carbon dioxide in the atmosphere

The earth's atmosphere near ground level is reasonably constant in its gaseous content. The following analysis by volume is usually accepted:

Nitrogen	78%
Oxygen	20.9%
Argon	0.9%
Carbon dioxide	0.02 to 0.04% (200 to 400 ppm)

The carbon dioxide content varies percentage-wise much more than do other constituents of the atmosphere. Of the gases in the air, CO_2 and oxygen are extremely important to plants and animals. Animals use oxygen and give off CO_2 while plants use both CO_2 and oxygen. The amount of carbon dioxide in the atmosphere varies by the hour, day, week, month and even year, and it varies greatly with location. In January 1959, the average CO_2 in the atmosphere at Fort Collins was approximately 255 ppm, while for the same period of 1960 the average level was 320 ppm. These variations are due to high and low pressure movements, storm fronts, wind and probably moisture release. The dotted line in Fig. 1 indicates the level of carbon dioxide outside the greenhouse for that particular day.

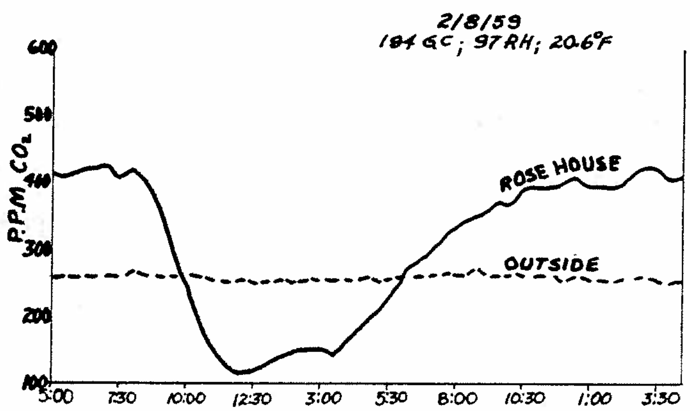

Fig. 1. The carbon dioxide concentrations in a rose greenhouse measured at 30-minute intervals on February 8, 1959. Total solar energy for the day -- 194 grm. cal/cm^2. Mean relative humidity outside -- 97%. Mean outside temperature -- 20.6°F.

Carbon dioxide inside the greenhouse

The amount of carbon dioxide inside greenhouses is much more variable than outside. In Fig. 2, the mean outside temperature, total solar energy and mean carbon dioxide level during daylight hours

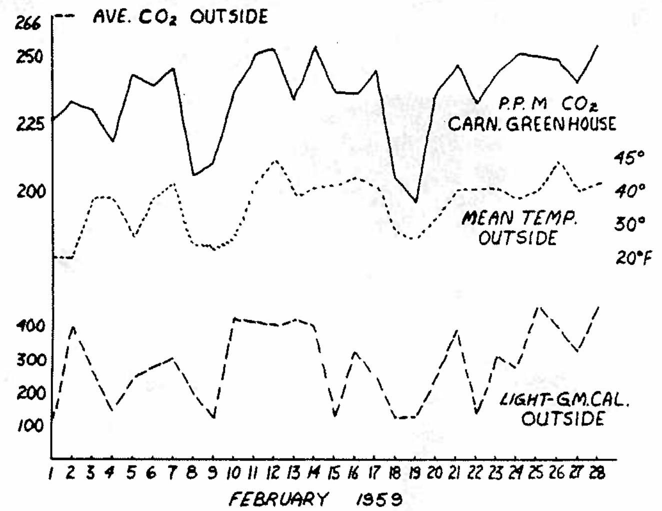

Fig. 2. Mean daily outside temperature, solar energy and CO_2 concentration during daylight hours inside a carnation greenhouse for the month of February, 1959.

are plotted for each day of February, 1959. The daily mean CO_2 level never reached that of outside air and fluctuated widely from below 200 ppm to above 250 ppm. The carbon dioxide level was lowest on colder days when light was also low (Feb. 9 and Feb. 18-19). However, carbon dioxide probably limited plant growth most of the month. This points up the possibility that carbon dioxide may be more of a limiting factor to plant growth than low light during the winter months. Even on darker days the plants assimilate sugar rather rapidly until low CO_2 limits the process (Fig. 1). A study of Fig. 1 prepared from one day's carbon dioxide measurements taken on a relatively cold, dark day, with no ventilation, shows that carbon dioxide limited sugar assimilation and growth most of the daylight hours. In other words, carbon dioxide was so low from 10:30 a.m. to 5:00 p.m. that the plants just about stood still so far as sugar assimilation is concerned. Had this day been warmer, ventilation during the day would have brought the CO_2 level up to nearly that of the outside air (Fig. 3). The typical carbon dioxide level in a carnation house is illustrated in Fig. 3 for a warm spring day when the solar energy available was just three times that for February 8 (Fig. 1). In Figure 3, the carbon dioxide level decreased rapidly following daybreak. Ventilating fans came on at 8:00 a.m. and brought the level up to almost that of outside air. Fans cut off between 3 and 4 p.m. when carbon dioxide decreased temporarily, then began increasing as light and CO_2 utilization began decreasing. It is obvious that ventilation is one of our best means of keeping carbon dioxide available to plants, at least in nearly the same quantities available in the outside atmosphere. Fan ventilation probably renews carbon dioxide at the leaf surface better than gravity flow ventilation.

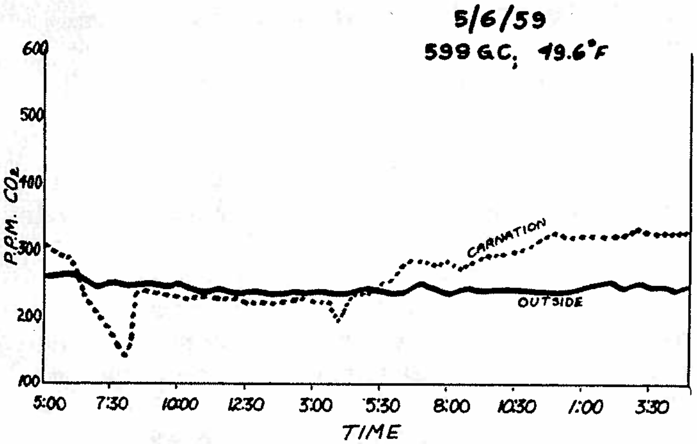

Fig. 3. The carbon dioxide concentrations in a carnation greenhouse measured at 30-minute intervals on May 6, 1959. Total solar energy for the day -- 599 grm. cal/cm^2. Mean outside temperature -- 49.6°F.

Researchers in the past have estimated that plants virtually stand still when the CO_2 level about them decreases to as low as 100 to 150 ppm. At about this point photosynthesis balances respiration and no dry matter is accumulated. Our work indicates that growth is materially slowed down at levels below 200 ppm.

Effects of increase carbon dioxide

For the past year work has been carried on in our research greenhouses to investigate possible influences on carnations from atmospheric fertilization with CO_2. Four completely air conditioned chambers of vinyl plastic were constructed. The carbon dioxide content of the atmosphere surrounding the plants is controlled independently in each of the 500 cu. ft. chambers. A positive air flow of approximately 4 ft./sec. is used in all chambers during light hours. In the first experiment levels of CO_2 of 200-300, 400, 500 and 600 ppm were supplied to Red Gayety carnations started June 30, 1959. Although this experiment has not been completed, the carbon dioxide concentrations have shown definite linear increases in yield of dry matter, number of breaks on plants, and total flower yield. The growth at higher CO_2 concentrations has been phenomenal. It appears that nutrient requirements will increase as the CO_2 concentration is increased around plants. In fact, with an increase of CO_2, a re-evaluation of optimum growing conditions (temperature, light, nutrients, etc.) may be in order.

Many problems have suggested themselves as this work has progressed. There seems to be no doubt that carbon dioxide can be used to obtain higher yields of higher quality flowers. When to add this gas to get the greatest benefits and how much to add are problems now being investigated.

The source of additional carbon dioxide used so far has been bottled gas. The cost of handling cylinders makes the price of bottled gas prohibitive. However, dry ice may be available from some distributors in a price range which would enable its use as a source of pure CO_2. We are also measuring the amounts of CO_2 given off by various organic mulches, and from the burning of carbon.

We wish to acknowledge the donation of appreciable supplies of bottled carbon dioxide by the Cardox Division of Chemetron Corp., 840 N. Michigan Ave., Chicago 11, Ill. We have also been given considerable gas flow metering equipment by the James B. Drummond Co., Denver, for speeding this work along.