CONTROLLED INJECTION OF CARBON DIOXIDE FOR ROSE PRODUCTION

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Enrichment of the atmosphere inside a greenhouse with carbon dioxide (CO_2) is widely used to increase both the quantity and quality of roses. A continuous monitoring and feedback control system for CO_2 injection should optimize the benefit of CO_2 enrichment for rose production while minimizing the associated costs. I describe the use of a commercially available infra-red gas analyzer that continuously monitors and controls the CO_2 concentration. As a case study, I describe its operation in a large single span greenhouse devoted to the production of roses.

Because the cost of supplying CO_2 is a minor part of the total production cost and there are few if any deleterious effects from overenrichment, there has been little effort by rose growers to maintain the concentration within narrow limits. The rate of CO_2 injection is adjusted by trial and error to give a concentration of 1000-1500 parts per million (ppm). The CO_2 is then injected continuously at this rate, and the atmosphere is sampled rarely if at all to see if the optimum concentration is being maintained. The CO_2 injection is only turned off at night or when the greenhouse is ventilated. Without knowing the CO_2 concentration, there is no sensible way to optimize its beneficial effect for rose production or to minimize the amount of CO_2 needed to get the optimum benefit.

There are horticultural benefits in controlling the injection of CO_2. Early in the morning or immediately after ventilation it is important to raise the CO_2 concentration quickly to take advantage of the high light level, since the beneficial effect of CO_2 on photosynthesis is much greater under high than low light conditions. To obtain high concentrations quickly requires controlled injection so that the CO_2 is shut off as soon as the appropriate concentration is reached; otherwise, the CO_2 concentration would quickly rise too high when the steady state condition is reached, e.g. when the rate of photosynthesis and leakage of CO_2 out of the greenhouse equals the rate of injection.

Costs of CO_2 are reduced by using controlled injection. The rate of CO_2 injection needed to maintain a specified concentration varies with the amount of light. On cloudy days when there is little photosynthesis the usual rate of CO_2 injection will gradually raise the concentration to a high level, often 2000-3000 ppm. On sunny days when photosynthesis is more rapid, the concentration of CO_2 is usually constant, because the consumption of CO_2 via photosynthesis equals the rate of injection that was determined for this condition. An injection rate that maintains an optimum level of CO_2 on sunny days will overenrich on cloudy days by a factor of two or more. The higher level of CO_2 is of little benefit to plant growth. In the laboratory the effect of CO_2 is most noticeable as the level is doubled from 330 ppm found outdoors to 600 ppm and doubled again to 1200 ppm. Another doubling to 2000 ppm or more does not further enhance growth. The overenrichment of CO_2 in cloudy weather wastes CO_2 because the leakage of CO_2 out of the greenhouse is accelerated when the concentration is higher inside. At levels above 1000 ppm the rate of leakage is at least proportional to the concentration of CO_2. Thus, if the concentration on cloudy days is twice the required level, a considerable fraction of the CO_2 is wasted.

I describe a device for controlling CO_2 injection whose operation is based on the principle of selective absorption of infrared radiation by CO_2. The model adapted to greenhouse use is hung vertically at or above the top of the crop. The surrounding air diffuses into the measurement chamber and the concentration of CO_2 in this air is converted to an electrical signal. The measurement is displayed on a meter calibrated in ppm CO_2 in the range of 300 to 3000 ppm. The controller has a knob calibrated in similar units to set the control level of CO_2. When the CO_2 falls below the control level, a relay is closed by the electronics as a thermostat closes contacts when the temperature falls. The relay can in turn operate a solenoid valve to control the flow of compressed CO_2 or propane to generate CO_2. Using this measurement and feedback control, the concentration can be regulated in the range of 400 to 3000 ppm CO_2 with an accuracy of +/- 100 ppm.

These devices are available from at least two suppliers in the USA. One is MDA Scientific, 1815 Glenview Avenue, Glenview, Illinois 60025, whose CO_2 controller, adapted for greenhouse use (Model ZFP1), is priced at $1100. This unit samples the ambient air by diffusion as described above. Another supplier is ES Industries, 8 South Maple Avenue, Marleton, New Jersey 08053, whose CO_2 controller, adapted for greenhouse use (Model TN591T29), is priced at $2000. This controller contains a suction pump and could be adapted to remote sampling, which is not possible with the other controller.

A completely different method measures the change in electrical conductivity of a solution when the atmosphere bubbled through the solution changes. A measurement device based on this principle can be constructed for about $200. Such a device is described in Hortscience 14, 180-182 (1979), A Low Cost Carbon Dioxide Analyzer for Greenhouses by B.A. Kimball and S.T. Mitchell. I am not aware of a device of this type that is commercially available for greenhouse use.

An estimate of the benefits accrued from feedback control of CO_2 enrichment can be calculated by examining the diurnal variation in the CO_2 level in a greenhouse devoted to rose production. The CO_2 was measured continuously for one week, March 5-11, 1982, in a greenhouse owned by William Pinchbeck Inc., Guilford, CT. He has two single span, single pane greenhouses containing 92,000 rose plants in 3.5 acres. CO_2 was provided as compressed gas and uniformly distributed throughout the houses using tygon tubing with small venting holes every 20 feet. The rate of injection for each house was controlled by a pressure regulator, and read on flow meters. On cloudy days the injection rate was set manually to 35% less than on sunny days. The injection was controlled by a time clock and was overridden if ventilation was required to keep the greenhouse cool. The CO_2 injection began at 7:00 a.m. and quit at 5:00 p.m. If ventilation occured, the injection was turned off until the next morning.

The CO_2 concentration was first measured during four days when the injection was not controlled and then for three days when the CO_2 analyzer was used as a feedback controller to turn off the injection if the CO_2 was above 1200 ppm. A record of the CO_2 levels during this period is shown in Figure 1. Note that the rate of injection was not changed in the last three days. Mr. Pinchbeck had previously checked the CO_2 concentration with a Kitagawa gas sampling kit. He had chosen a suitable setting for the injection rate on sunny days with the vents closed because the CO_2 concentration leveled out at 1200 ppm. With this injection rate, however, it took an hour to reach 1200 ppm from 800 ppm found at dawn. If the CO_2 were turned on after a short period of venting at midday, it would take two hours or more to bring the concentration up to 1200 ppm from the 330 ppm outside. Thus, even with careful management of CO_2 injection there were periods of the day when the benefits of CO_2 enrichment were lost.

On cloudy days, without feedback control, the CO_2 concentration eventually rose to 2000 ppm, about twice the required level. With the controller in operation

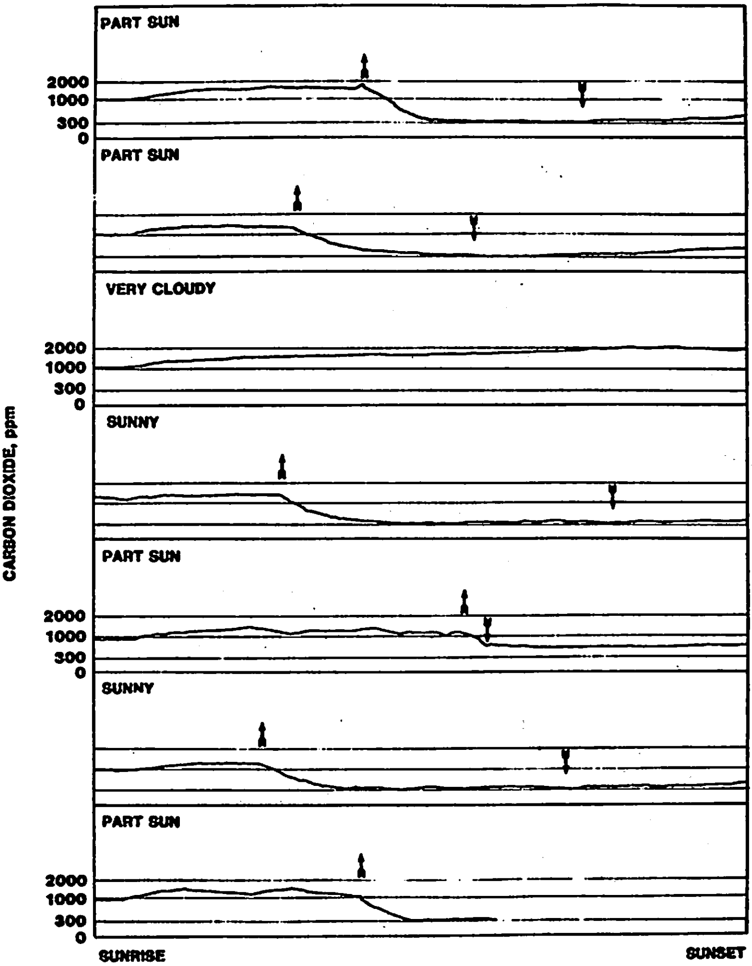

Figure 1. A record of the CO_2 levels in the greenhouse during the day for March 5-11, 1982. During the first four days, upper panels, the CO_2 analyzer and controller only measured the CO_2 but did not control it. The controller did turn the CO_2 injection on and off the the last three days. The up arrows indicate when the vents opened and the injection was turned off. The down arrows indicate when the vents closed. Respiration from the plants and the soil increased the CO_2 at night, even without CO_2 injection.

the CO_2 never went so high during cloudy periods because the injection was cycled on and off to hold the control level. In this situation the controller saved a substantial amount of CO_2 that would otherwise have been lost due to leakage to the outside. On cloudy days when the CO_2 controller was not in operation, the average level of CO_2 was 1800 ppm or 50% higher than the set point. Since the amount of CO_2 used to maintain the higher level was at least 50% greater than that required to reach 1200 ppm, the controller saved one third of the CO_2 on cloudy days without reducing the benefit of enrichment.

If the injection of CO_2 had been increased while under feedback control, the level could have been raised more quickly to the control level early in the morning or after venting. This would have resulted in additional beneficial effects of CO_2 during those times when the light was bright. Since CO_2 would have been applied at the most suitable times for increasing photosynthesis, the additional benefit would outweigh the slight extra cost of CO_2 injection during these periods. A quantitative determination of this benefit will have to await a longer study of yield in which CO_2 enrichment would be used with and without feedback control.

William Pinchbeck Inc. uses between 30 and 40 tons of CO_2 per year during the cloudy winter months of October through March. He currently pays $180/ton for compressed CO_2, a price competitive with CO_2 generation from propane gas at $1.30 a gallon. If half the days during the months of CO_2 enrichment are cloudy, then a CO_2 controller may save between 15 and 25% of the costs of CO_2 enrichment and thus repay the investment in an analyzer and controller in one or two years.