A CO_2 MONITORING AND CONTROL SYSTEM
FOR PLANT GROWTH CHAMBERS[1]

DAVID T. PATTERSON AND JOHN L. HITE

Botany Department and Phytotron, Duke University, Durham, North Carolina 27706

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The concentration of CO_2 in growth chambers filled with plants often is depressed far below normal. It is impractical to prevent this by adding outside air because the large volume required places an excessive load on the air conditioning. The best remedy is the addition of CO_2 from a compressed gas tank, and this paper describes monitoring and control equipment which can maintain growth chamber CO_2 concentration within $\pm 7\%$ or less of the normal ambient concentration. By use of an infrared gas analyzer and strip chart recorder the CO_2 concentration can be recorded and controlled at a number of stations.

Most plant growth chambers are equipped with some means of introducing air from outside to prevent the CO_2 concentration from falling to excessively low levels. In both units of the Southeastern Plant Environment Laboratories (SEPEL) these provisions were found to be insufficient for growth chambers filled with large plants. For example, the A-chambers of SEPEL, which are 3.65 x 2.43 x 2.13 m and contain 18.9 m^3 of air, have a theoretical input of fresh or makeup air sufficient to produce a turn-

over of approximately 1% of their volume per minute (Downs *et al*, 1972). Nevertheless, a crop of cotton plants can rapidly deplete the CO_2 concentration of an A-chamber to 150 ppm and corn to 50 ppm although the outside air contains 350 ppm. Materially increasing the rate of introduction of fresh air increases the load on the air conditioning equipment and decreases the precision of control of the chamber environment. Therefore, the most practicable method of maintaining the CO_2 concentration at a desired level appears to be controlled injection of CO_2. A system which continuously monitors the CO_2 concentration in several growth chambers and greenhouses has been designed and installed at the Duke University unit of SEPEL. The system also provides automatic CO_2 supplementation to maintain CO_2 at approximately normal levels.

MATERIALS AND METHODS

Sampling System. Air samples are drawn from the chambers and greenhouses through polypropylene tubing to a central control panel (fig. 1). Equal flow rates in the sample lines are maintained by use of flow meters and needle valves on the control panel. Each sample line is connected through a three-way solenoid valve to two separate manifolds. When the solenoids are not energized the sample air passes into an exhaust manifold and exhausts through a large pump which runs continuously to purge the sample lines and prevent contamination of one sample by the previous sample. When a solenoid is energized it diverts the air sample into the sample manifold which is connected to a small diaphragm pump. This pump draws air from only one sampling station at a time, depending on which solenoid is energized, and pumps the air sample through the CO_2 analyzer (Beckman model 864). A strip chart recorder monitors the signal from the CO_2 analyzer. A similar sampling system was described by Burrage (1972).

The sampling sequence and timing are controlled by a stepper switch which is activated by a cam timer every two minutes (fig. 2). The stepper switch energizes sequentially the three-way solenoids thus diverting samples from each station consecutively into the analyzer. Each sample station is monitored for a 2 minute interval during each cycle of the stepper. At present, three chambers, three greenhouses, and one air duct are monitored, the air from each being sampled once every 14 minutes. Manual override switches allow continuous monitoring of any one point by bypassing the cam timer and holding the stepper switch on a particular point.

Supplementation System. A two-way normally closed solenoid valve at each chamber and greenhouse controls the input of supplemental CO_2 from a compressed gas cylinder. Each solenoid valve is wired through both a cam-activated switch on the recorder pen drive mechanism and the stepper switch which controls the three-way solenoids on the sample lines. When the signal from the CO_2 analyzer falls below the set point, the contacts on the recorder cam switch close, allowing current to pass through the closed contacts of the stepper switch. This energizes the two-way solenoid valve on the injection line at the corresponding sampling station. Supplemental CO_2 is then added until the CO_2 level reaches the set point or the stepper switch breaks the circuit. The maximum time for CO_2 input is the same as the sampling time, two minutes on each cycle. The input of supplemental CO_2 is further controlled at the inlet to each chamber and greenhouse by a flow meter and needle valve.

As some of the chambers operate at high humidities and at temperatures above room temperature, condensation can occur in the sample lines. To avoid this, it was necessary to either dry the air or raise the temperature of the sample lines above the dew point of the air samples. Because a dew point hygrometer is installed periodically in the system to monitor humidity, we decided to heat the sample lines rather than dry the air. This was accomplished by running a resistance heating wire (copper chromium, 1.5 ohm per m) inside each sample line and connecting it through a rheostat to line current (115 v) to supply 7.5 watts per m.

RESULTS

Figures 3 and 4 show the diurnal variation in CO_2 concentration in an A-chamber without and with the controlled injection of CO_2. This chamber contained 59 small cotton plants (*Gossypium hirsulum*, var. McNair 511) with a total leaf area of approximately 10 m². Light intensity at plant level was 44,000 lux and daytime temperature was 28°C. Without any control (fig. 3), the CO_2 concentration in the chamber began to decrease rapidly about 4 minutes after the lights came on at 8 a.m., and fell to 260 ppm within the first hour. When a staff member entered the chamber at 9 a.m. to water the plants, the CO_2 concentration increased rapidly to about 350 ppm. After watering, which required about 5 minutes, the CO_2 concentration once again decreased rapidly, reaching 215 ppm by 10:30 a.m. The CO_2 concentration decreased more slowly after 10:30 a.m. and had fallen to about 195 ppm by 3:50 p.m., when the plants were again watered. During this sec-
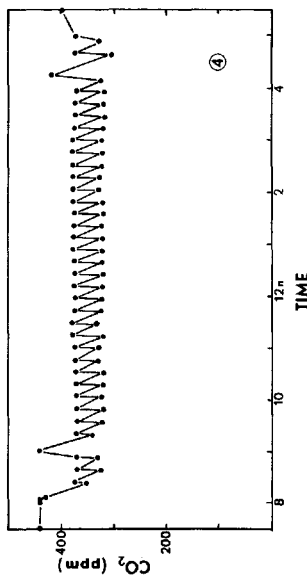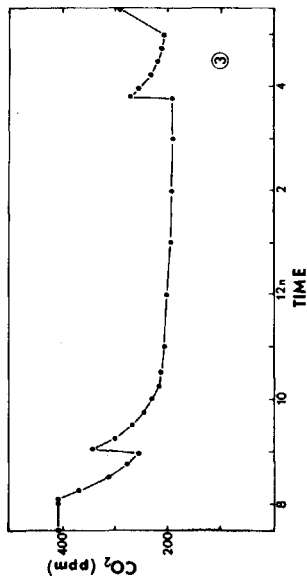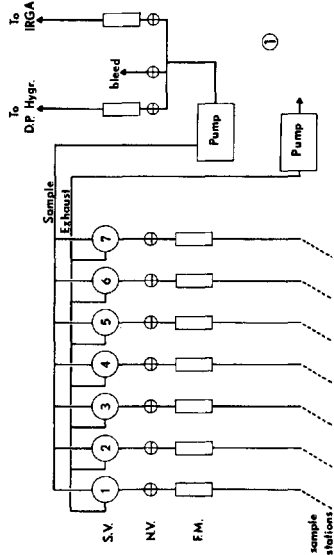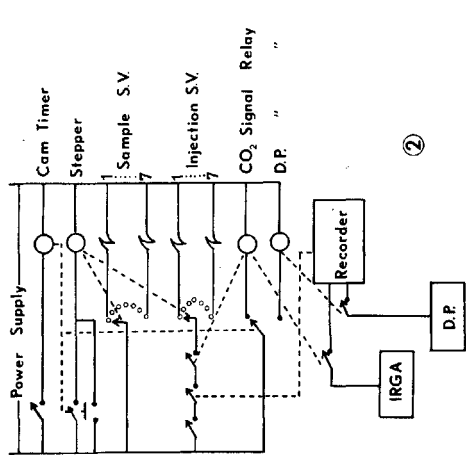
FIGURES 1 and 2.   Central control panel and electrical circuit diagram for CO_2 monitoring and control system. In Figure 2, solid lines are electrical connections and dashed lines indicate mechanical connections.   S.V. = solenoid valve, N.V. = needle valve, F.M. = flow meter, D.P. = dew point hygrometer, IRGA = infrared gas analyzer.
FIGURE 3.   Diurnal variation in CO_2 concentration in a growth chamber without controlled injection of CO_2.
FIGURE 4.   Diurnal variation in CO_2 concentration in the same chamber with CO_2 control in operation.   (Compare to fig. 3).

ond watering the CO_2 concentration increased rapidly to 270 ppm and after watering decreased again. The chamber lights switched off at 5 p.m. and the CO_2 level then increased toward the nighttime maximum of 400 to 450 ppm.

With the CO_2 injection system operating (fig. 4) the CO_2 concentration was maintained within ± 25 ppm of the set point (350 ppm) throughout the day except for short increases in CO_2 when the plants were watered. The CO_2 injection pulse occurred every 14 minutes, and lasted about 1 minute (at an injection flow rate of 1.0 $l$pm). After each injection, the CO_2 level was depleted at a rate of about 3 to 4 ppm per minute.

DISCUSSION

This CO_2 sampling and control system is well suited to maintaining CO_2 level within relatively small limits about a fixed set point. The fineness of control depends on the rate of depletion of CO_2 by plants in the chamber. There was no difficulty in maintaining the chamber CO_2 concentration above a minimum level even with a large number of large plants in the chamber. Used in this way the system functions as a supplemental rather than as a control system. For applications requiring finer control of CO_2 concentration, a shorter sampling interval could be used. This would result in a smaller change in CO_2 during each cycle since during each pulse only enough CO_2 must be injected to last until the next pulse. If, for example, the sampling time was reduced to 30 seconds, each of the seven stations would be sampled every 3.5 minutes. At a rate of depletion of 3 ppm per minute, this would allow control over a range of 10

to 12 ppm (350 ppm ± 5 or 6 ppm) provided that adequate mixing occurred. Shorter sampling times might provide for the accommodation of a larger number of chambers in the control system if precautions were taken to assure rapid mixing of CO_2 with the atmosphere in the chambers. On a 30-second interval, 30 chambers could be sampled every 15 minutes and CO_2 could be injected in 30-second pulses into each chamber at 15 minute intervals. For our present system, we chose the 2-minute sample time because the dewpoint hygrometer requires 1.5 to 2 minutes to reach a stable reading.

In addition to its use for sampling and supplementation, the system offers the potential for estimating the CO_2 uptake rates of crops of plants in growth chambers. Preliminary results indicate that a chamber may be treated as a closed system of constant volume and the rate of CO_2 depletion by the chamber crop can be determined after corrections are made for CO_2 leakage.

LITERATURE CITED

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