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CO_2 from gas-fired heating boilers - its distribution and exchange rate*

N. van Berkel

Glasshouse Crops Research and Experiment Station, Naaldwijk, the Netherlands

Summary

CO_2 measurements were carried out on two tomato and two chrysanthemum nurseries on which CO_2 generated by the gas-fired heating boilers was used for CO_2 enrichment. The CO_2 contents may vary a great deal in the course of a day, from 300 to 6000 ppm. Where a main duct with lay flats (perforated plastic tubes) was used, the CO_2 gradients were measured along the plastic tubes. This system of distribution was shown to give fewer variations than the more primitive system of a main duct with holes through which the CO_2 is fed into the glasshouse. The latter system produced a more pronounced gradient with tomatoes than with chrysanthemums.

No differences were recorded in the CO_2 contents at various heights in the glasshouse. Only in the case of chrysanthemums where a main duct with lay flats was used could a difference be found in the CO_2 levels in and outside the beds.

Calculations were made of the exchange rates of glasshouse air with the ventilators closed. A close relationship was found between the exchange rates and the wind speed. The exchange rates varied from 0.2 to 1.4 times per hour. Opening of the ventilators caused a sharp decrease in the CO_2 content. Relatively the strongest effect was noted for the first few centimetres of opening the ventilators.

Introduction

Since the end of 1971, Dutch growers have been changing over wholesale from atomising paraffin burners for CO_2 enrichment to gas-fired boiler installations. The switch is taking place simultaneously with the change-over from oil to natural gas for heating purposes.

Instead of using a decentralized system of separate burners growers are now using central boiler installations which provide heating as well as CO_2. Part of the boiler combustion gases is extracted with the aid of a primary fan. A secondary fan adds air to the combustion gases and feeds the gas mixtures which contains 2 to 3 % CO_2 into the main duct which runs from the boiler house to the glasshouses. Further distribution takes place via lay flats (perforated plastic tubes) which run at right angles to the main duct into the glasshouses.

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When the new distribution system was introduced, the question cropped up whether a network of lay flats was really necessary. Would not openings in the main duct serve the same purpose which would be much more convenient for lettuce and flower crops. Older questions like 'what is the vertical CO_2 distribution in the glasshouse' and 'what is the effect of ventilation' were also being asked again.

To find answers to these questions, CO_2 measurements were carried out on two commercial tomato and chrysanthemum nurseries, with the aid of self-registering measuring apparatus.

Materials and methods

In 1973 and 1974, the CO_2 levels were measured in 4 glasshouses on 4 nurseries. The houses were of the multispan type with a bay width of 3.2 m, a gutter height of about 2.5 m and a ridge height of about 3 m. Two of the houses were used for growing tomatoes, the other two for chrysanthemums. In the tomato houses the plants were spaced at 45 cm in the row and 80 cm between the rows. The heating pipes were installed below the gutters and the ridge at a height of 30 to 60 cm.

The chrysanthemum plants were grown in beds of 1.25 m wide, separated by paths of 0.35 m wide, and at a plant density of 58 to 62 plants per m². The heating pipes were installed at a height of 1.8 m below the gutters only.

The CO_2 was transported via one main duct suspended above the main central path, or via two main ducts running along opposite gables (Fig. 1). Further distribution took place via a number of 35 m long lay flats, running from the main duct into the glasshouse at a spacing of one tube to each bay.

The lay flats were removed if unrestricted CO_2 distribution was required. In that case the gas moved from the main duct openings into each glasshouse bay in a horizontal direction. If necessary, short, flexible laterals were fitted to the main duct so that the gas stream could be directed amongst or over the crop.

The CO_2 levels were measured with two IRGA's, each having six measuring points. The results were registered by a recorder. The measuring points for the horizontal measurements were just above the crop, at a height of 1.8 m for toma-

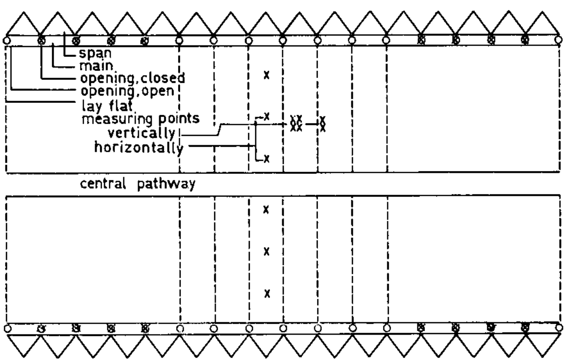

Fig. 1. Plan of a distribution system consisting of two main ducts with lay flats (perforated plastic tubes), showing the position of the CO_2 measuring points. An alternative system may be obtained by installing one main duct above the central pathway, instead of two main ducts along the gables.

toes and at 0.8 m for chrysanthemums. For the vertical measurements in the tomatoes there were four points at regular intervals between the glasshouse floor and the roof of each bay. In the case of chrysanthemums, the lowest measuring point was in the middle of a bed with the other points above.

The gas for analyses was fed via 35 m long butyl rubber hoses from the sampling areas to the IRGA's. The IRGA's were calibrated at regular intervals with N_2 and with standard gas mixtures.

The measuring points were arranged in the two central bays of a 6-bay measuring area. Variations in the methods of CO_2 enrichment were made over the whole area. CO_2 enrichment was blocked in four bays to the left and the right of the measuring area in order to prevent any effect of the neighbouring bays on the measuring area (Fig. 1).

For the determination of the effects of variations only those periods were compared in which the CO_2 level had become steady and the other factors did not change quantitatively. From the available data a choice was made in such a way that the results presented give an average picture of the measurements collected.

Results and discussion

The pattern of CO_2 levels in the course of a day

Fig. 2 gives a clear impression of how much the CO_2 levels may vary in the course of a day. The levels recorded ranged from 300 to 6000 ppm. The pattern shows strong fluctuations. Two factors which have a very great effect on this are the opening of the ventilators and the starting and stopping of the burner. Fig. 7 shows how great the effect of the ventilator opening can be.

Another two factors which may have an important effect, but which had nothing to do with the fluctuations shown in Fig. 2, are changing wind speed and changing direction of the wind. Research into the factors which influence CO_2 levels is made difficult by the great fluctuations. To carry out such an investigation, all the factors which are not the subject of the experiment should remain constant. Because of the

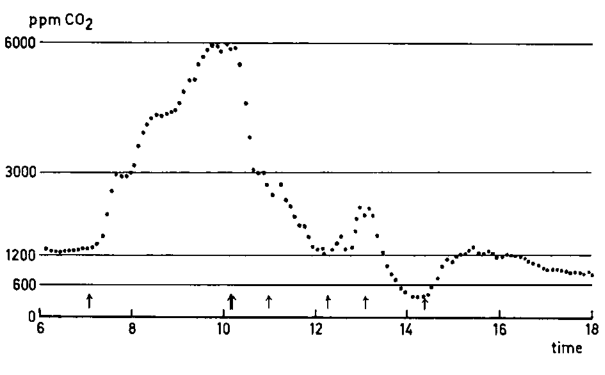

Fig. 2. Course of the CO_2 levels on a day picked at random. The single arrows indicate changes in the operation of the burner; the double arrows indicate opening of the ventilators.

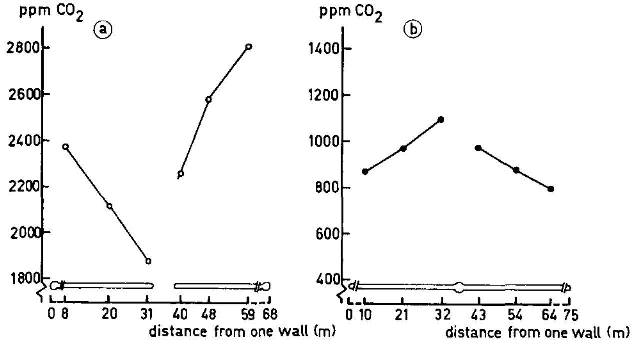

Fig. 3a. Gradient of the CO_2 levels with a system with two main ducts along the gables and lay flats.
Fig. 3b. The same with a central main duct and lay flats.

fluctuations it is impossible to speak of *the* diurnal CO_2 level and it would be better referred to as the *average* daily CO_2 level.

The horizontal pattern of CO_2 levels in a glasshouse bay

For the study of horizontal and vertical CO_2 gradients, the only data used were those obtained with open ventilators. The reason for this is that the data obtained from similar measuring points in two adjoining bays showed a greater similarity when the ventilators were open than when they were closed. The variations found with closed ventilators are probably caused by air currents set up by the wind in a closed glasshouse.

If the lay flats run from opposite gables to the middle of the glasshouse, the CO_2 distribution pattern generally looks like that shown in Fig. 3a. The CO_2 levels decrease from one gable to the centre of the glasshouse and they increase again towards the opposite gable. The same pattern in reverse is found where CO_2 is distributed from lay flats running from a main above the central pathway to the gables (Fig. 3b). There is no difference between the CO_2 distribution patterns in tomatoes and those in chrysanthemums. Less CO_2 is measured the further one is removed from the main duct.

According to measurements made by Vente (1974), the total quantity of CO_2 supplied through lay flats, as used for the present measurements decreases relatively with the length of the tube. With an initial pressure of 30 mm water column, the openings at the end of the lay flat supplied 13 % less CO_2 than the openings at the beginning of the tube. At 60 m length the reduction is of the order of 35 %.

In our investigation the tubes were 35 m long and the CO_2 distribution pattern measured by us is certainly to a large extent the result of decreasing CO_2 supply at increasing distances from the main duct. Nevertheless, the reduction is often much

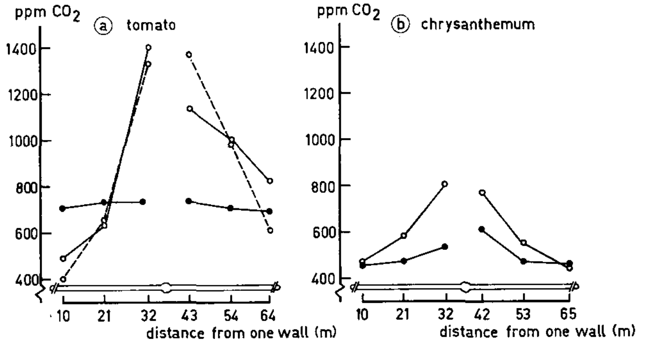

Fig. 4a. Horizontal gradient of the CO_2 levels in a tomato crop, using a central duct with:
●——● lay flats at soil level;
o——o openings at 10 and 20 cm above the crop;
o - - - o openings at half the height of the crop.
Fig. 4b. The same in a chrysanthemum crop with:
●——● lay flats at soil level;
o——o openings 1.2 m above the crop.

greater than may be explained with the values found by Vente. One explanation may be the variation found in the ventilator openings from the gables to the central path or vice versa. The interruption in the CO_2 tubes at the central path may also have an effect on the distribution pattern.

CO_2 distribution via tubes and free openings

As Fig. 4a shows, the gradient of the CO_2 levels measured over a tomato crop was much greater if the CO_2 was released from the main duct than via lay flats. Amongst the crop this effect was even more pronounced. Much the same pattern was found with chrysanthemums, but the variations were not quite as great (Fig. 4b).

The strong gradient obtained with the free release of CO_2 from the main duct as probably partly caused by CO_2 losses to the outside as a result of cross currents from the open ventilators.

The height of the main duct openings and the space between the top of the crop and the glasshouse roof were probably responsible for the greater gradients found with tomatoes than with chrysanthemums. In the case of tomatoes, the CO_2 stream was released at 10 to 20 cm above the top of the crop which may well have caused some resistance. With the chrysanthemums, the CO_2 stream was released at a height of 1.2 m above the crop. The flow path between the glasshouse roof and the top of the crop was also narrower in the case of the tomatoes, about 0.9 m, as against 2.0 m with the chrysanthemums. The CO_2 current must have met with relatively more resistance in the tomato crop than in the chrysanthemums.

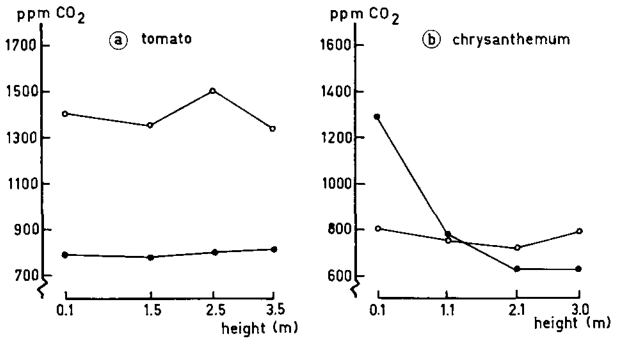

Fig. 5a. Vertical gradient of the CO_2 levels in a tomato crop, using a main duct with:
●——● lay flats at soil level;
o——o openings at 10 and 20 cm above the crop.
Fig. 5b. The same in a chrysanthemum crop with:
●——● lay flats at soil level;
o——o openings at 1.2 m above the crop.

Vertical gradient of CO_2 levels

Again, only the data obtained with open ventilators were used. No clear differences in the levels of CO_2 at various heights were found in the tomato crop, irrespective of whether the CO_2 was applied via lay flats or released directly from the main duct (Fig. 5a). Much the same picture was obtained with chrysanthemums (Fig. 5b), except that where CO_2 was applied via lay flats, the levels amongst the crop at 10 cm were clearly higher than at other points above the crop. The difference in the vertical gradients in tomatoes and chrysanthemums were probably caused by two factors, plant density and position of the heating pipes.

Plant density. With 2.7 plants per m^2, the tomato crop has a low plant density, whereas chrysanthemums have a very high plant density at 58 to 62 plants per m^2. In the case of chrysanthemums this may lead to stagnation of the air amongst the plants and the CO_2 emitted by the lay flats is slow to circulate amongst the plants. The result is a gradient between the measuring points amongst and above the crop.

Position of the heating pipes. The low level of the heating pipes in the tomato crop, 30 to 60 cm, tends to encourage greater movement of the air and therefore better mixing of the CO_2 with the air. This is not the case with the chrysanthemums where the heating pipes are at a height of 1.8 m.

Measurements made at 10 and 80 cm above the path between the chrysanthemum beds showed differences between the CO_2 levels of the same order as those recorded between the measuring points amongst and above the crop. The exchange rate is apparently as low in the paths as it is in the beds. The theory of stagnated air movement in beds and paths is confirmed by the fact that CO_2 levels

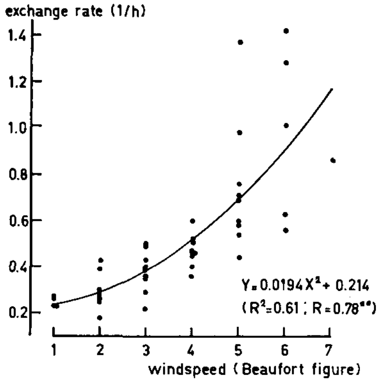

Fig. 6. Relationship between the wind speed (Beaufort figure) and the exchange rate of CO_2 (1/h) in an aluminium-wooden multispan.

recorded amongst the chrysanthemum crop at night were always a little higher than at other measuring points.

With the free release of CO_2 from the main duct there was no gradient from amongst to the outside of the crop. This appears to be the result of slow penetration of the CO_2 stream into the crop.

Exchange rate

With closed ventilators. At the end of the day when the CO_2 supply was stopped, the CO_2 content in a glasshouse decreased gradually, showing a curved pattern. Eventually the minimum level was reached which was more or less above the CO_2 level in the open. The nightly coarse of the CO_2 levels offered the possibility of calculating the exchange rate of a glasshouse.

The calculation was carried out with the aid of the formula worked out by Businger (1963).

$$S = -(1/t) \ln (C_g - C_0)/(C_s - C_0)$$

in which S represents the exchange rate, expressed as the number of air changes per hour (1/h).

t = time in hours

C_g = prevalent CO_2 level (%) in the glasshouse

C_s = the initial concentration (%) in the glasshouse

C_0 = the CO_2 concentration outside (%) (for this the value was chosen of the ultimate CO_2 level. The value is the balance between the CO_2 supply as a result of respiration of the soil and the crop and the CO_2 loss through exchange).

For a glasshouse with closed ventilators the exchange rates ranged between the extremes of 0.18 and 1.42. The values appeared to depend on the wind speed (Fig. 6). The relationship may be expressed as $Y = 0.0194 X^2 + 0.214$ in which X represents the wind speed (in Beaufort figures) and Y the exchange rate. The correlation R = 0.78 proved to be very significant ($P < 0.01$), so that 60 % of the variance could be explained with this expression. In other glasshouse values for exchange rates were found of the same order of magnitude as those mentioned above. The lowest value obtained is similar to the lowest value recorded by Okada & Takakura (1973). They found a value of 0.21 for an aluminium glasshouse, but the difference was that with increasing wind speeds they found exchange rates which increased much more sharply than in this case. At a windspeed of 3 Beaufort they recorded values ranging from 1.02 to 1.38, compared with 0.22 to 0.50 in this experiment. Their glasshouse was obviously less air-tight.

The calculated low exchange rates are no doubt the result of developments in glasshouse construction which have taken place in the Netherlands in the past ten or twenty years. During this time there has been a change from the wooden Dutch light houses via the wooden and metal clad houses to aluminium glasshouses. The extent of glass overlaps and leaks has been reduced at the same time with the result that the exchange of glasshouse air has decreased.

At lower exchange rates, the CO_2 levels will tend to be relatively high, as will the levels of possibly harmful gases. On the other hand, in the absence of CO_2 enrichment the CO_2 levels in the glasshouse may easily drop below 0.03 %.

The loss of water vapour is also made very difficult by low ventilation rates. This may lead to high levels of atmospheric humidity, particularly if the difference between the outside temperature and the temperature in the glasshouse is small. In this case the second way of water vapour loss, by condensation against the glass, becomes largely inoperative.

The result then is an increased risk of fungal diseases.

With open ventilators. The CO_2 content drops sharply when the ventilators are opened (Fig. 7). Even a small ventilator opening has a great effect. Continued opening of the ventilators has a relatively smaller effect. As the CO_2 levels in the glasshouse are in fact the result of the difference between supply and loss of CO_2,

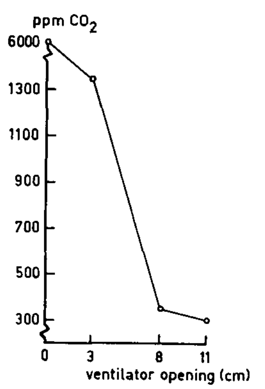

Fig. 7. CO_2 levels in an aluminium clad multispan with closed ventilators and ventilators opened to 3, 8 and 11 cm.

it appears that the exchange rate is greatly increased by opening the ventilators. The first few centimetres of ventilator opening produce the largest relative increase.

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