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A COMPARISON OF TWO TECHNIQUES FOR CO_2 ENRICHMENT IN GREENHOUSES IN REGIONS WITH HIGH LEVELS OF SOLAR RADIATION*

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ZIPORI I., DAYAN E. and ENOCH H. Z. *A comparison of two techniques for CO_2 enrichment in greenhouses in regions with high levels of solar radiation.* BIOTRONICS **15**, 9–14, 1986. At the Besor Experiment Station, Israel, two techniques for the enrichment of greenhouses with carbon dioxide were tested and compared with non-enriched growth of tomatoes. With one enrichment technique CO_2 was applied only during those parts of the day when the temperature in the closed greenhouse did not exceed 30°C (selective enrichment). With the other technique, CO_2 was applied also during those parts of the day when the temperature would have exceeded 30°C, by intermittent cycles of enrichment (greenhouse closed) and aeration (greenhouse open). The effect of each technique on yields was tested in identical greenhouses, in which a local and a Dutch-bred variety of tomato was grown. In both varieties higher yields were obtained with intermittent enrichment compared with selective enrichment or with no enrichment.

Key words: *Licopersicon esculentum* Mill.; tomato; carbon dioxide enrichment; greenhouse; solar radiation; fruit yield.

INTRODUCTION

The high levels of solar radiation in Israel in general, and in the Besor region in particular, indicate that enrichment of greenhouses with carbon dioxide may have a high potential with regard to its effect on photosynthesis rates and, consequently, on dry matter production. The growing season of greenhouse tomatoes in Israel is from the beginning of October until the end of March or even April. On most days (about 75%) of the growing season, the sky is clear and radiation levels are high. The lowest levels of global radiation measured around December 20 were 11 MJ m^{-2} day^{-1} on clear days. These high radiation levels indicate a high theo-

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retical enrichment potential. However, they also cause a relatively rapid increase in temperature and relative humidity inside the greenhouse after it is closed for enrichment (*3*, *4*).

During the process of enrichment, the greenhouse is kept closed in order to maintain the required high levels of CO_2 in its atmosphere. However, because of the low heat capacity of the air and the high radiation levels, high temperatures are reached in the greenhouse within a short time of closing. Under high temperatures (above 30°C) and relative humidities, fruit setting and development are adversely affected, as are some fruit quality components (*1*). The occurrence of some fungal diseases may increase and some physiological processes in the plants may be hampered.

In some enrichment studies, carried out in Israel, the investigators proposed to overcome the problems of excess heat and water vapour accumulation in a greenhouse during enrichment in various ways: Shading—to reduce the amount of radiation penetrating the greenhouse (*4*); selective enrichment—to enrich only during the morning and the afternoon hours, when radiation levels are relatively low (*3*). Selective radiation—by filtration and storage of those wavelengths of the solar radiation spectrum not necessary for photosynthesis (the process is being investigated now at Ben-Gurion University); intermittent enrichment—at the Besor Experiment Station this technique has been studied for some time (*2*), and it is hoped that this technique will enable the enrichment of greenhouses also when radiation levels are high and photosynthesis rates are at their maximum.

In the present work two enrichment techniques and their practical value for growers were compared: selective enrichment—as applied today by many rose growers in Israel, and intermittent enrichment.

MATERIAL AND METHODS

The experiment was done in three identical greenhouses (one greenhouse per technique plus a control, without enrichment) of the "Sharsheret" type, with a glass-covered roof and double layer, 0.1 mm-thick polyethylene side walls. Air could be blown into the space between the layers to increase isolation, and the side walls could be rolled up mechanically or manually. The area of each greenhouse was 600 m^2. Tomato "Speedlings" were planted on Oct. 6. '82, at a density of 3 plants m^{-2}, with two varieties in each greenhouse: K-111 (local line) and 4884 (Dutch line). Water and fertilizer were applied via a drip irrigation system. All agrotechnical activities were as common in the region and according to recommendations of the Israeli Extension Service. CO_2 enrichment started about a month after planting and the different techniques are detailed below.

Selective enrichment

With this technique, CO_2 enrichment was started in the morning, when the radiation level outside the greenhouse exceeded 200 W m^{-2}. Enrichment ceased when the temperature in the greenhouse reached 28°C and the greenhouse was opened for aeration. CO_2 application was resumed in the afternoon, when temperatures and radiation levels decreased and continued until the radiation level was below 200 W m^{-2} at which point it was stopped for the night (Fig. 1). The CO_2 source in this technique was domestic gas (a butane-propane mix) burnt in an oven outside the greenhouse. The CO_2 produced was cooled and blown into the greenhouse with an air convector installed inside. CO_2 level was monitored with an infrared gas analyzer (type Uras 2, Hartmann & Braun, W. Germany) and was maintained at 1000 ± 200 vpm. On cloudy days enrichment was maintained throughout the day apart from short periods when the greenhouse was aerated to get rid of excess humidity and reduce the chances of development of fungal diseases.

Intermittent enrichment

With this technique, CO_2 was applied as described above (selective enrichment) until the temperature in the greenhouse reached 28°C and aeration took place. After 10–20 min of aeration, if the temperature was below 24°C, the greenhouse was closed and CO_2 was injected, reaching a level of 1000 ± 200 vpm within 60–90 s. Usually, after a period of 10–30 min of enrichment, the greenhouse was again aerated (28°C being the maximum permissible temperature), and so forth. On cloudy days the greenhouse was closed for longer periods due to a lower temperature increase rate. The CO_2 source in this case was compressed commercial gas, which enabled the rapid increase in CO_2 concentration in the greenhouse (Fig. 1).

Control

In the control greenhouse no CO_2 was applied and the aeration regime was identical to the one described in section 1 (selective enrichment).

RESULTS

The cumulative fresh fruit yields of the two varieties tested are presented in Figs. 2 and 3. In both varieties yields were higher with intermittent enrichment than with selective enrichment or no enrichment (control). The response of line 111 to intermittent enrichment was weaker than that of line 4884. Selective enrichment did not have any effect on yield in line 111 in comparison with the control.

Figure 4 presents the photosynthesis rates measured under different radiation levels in the greenhouse where CO_2 level, temperature and relative humidity were continuously changing. A detailed description of the measuring technique has been given by Dayan *et al.* (*2*). Enrichment with CO_2 did not increase photosynthesis rates before the radiation level outside the greenhouse reached approximately 200 W m^{-2} (about 130 W m^{-2} inside), as under these radiation levels light intensity is the limiting factor for photosynthesis. Above the 200 W m^{-2} level, CO_2 enrichment increased photosynthesis rates. In the non-enriched (control) greenhouse, maximum photosynthesis rates were attained when the radiation level was approximately 400 W m^{-2}. A further increase in light intensity did not raise photosynthesis rates. In the CO_2-enriched greenhouse, photosynthesis rates did not attain their maximum level even when the radiation level reached 600 W m^{-2}, which was the maximum value measured that day. This indicates that the same rates of photosynthesis can be obtained also under CO_2 concentrations lower than the 1000 vpm maintained in this study.

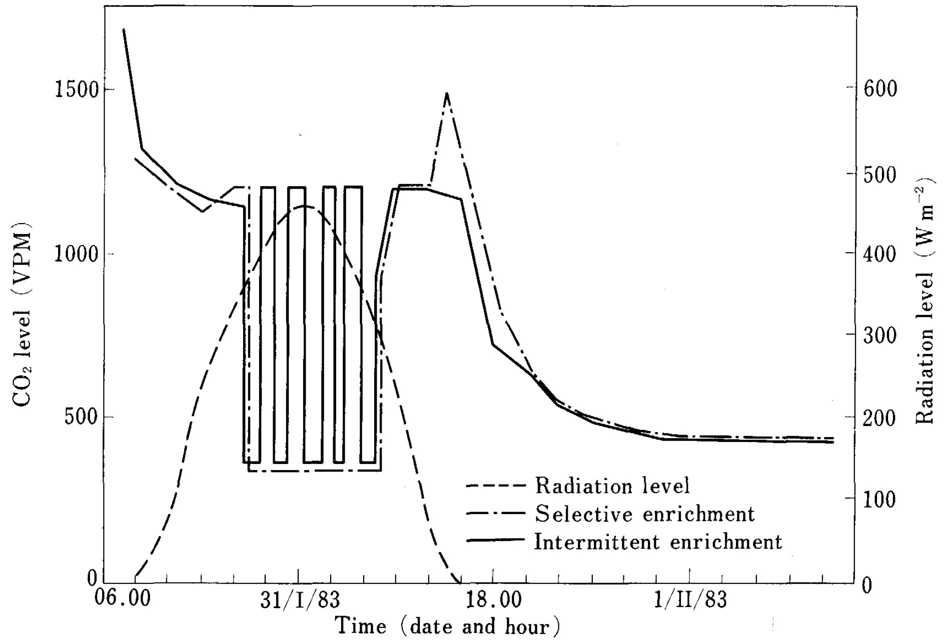

Fig. 1. Daily course of radiation and CO_2 levels in the different enrichment techniques studied.

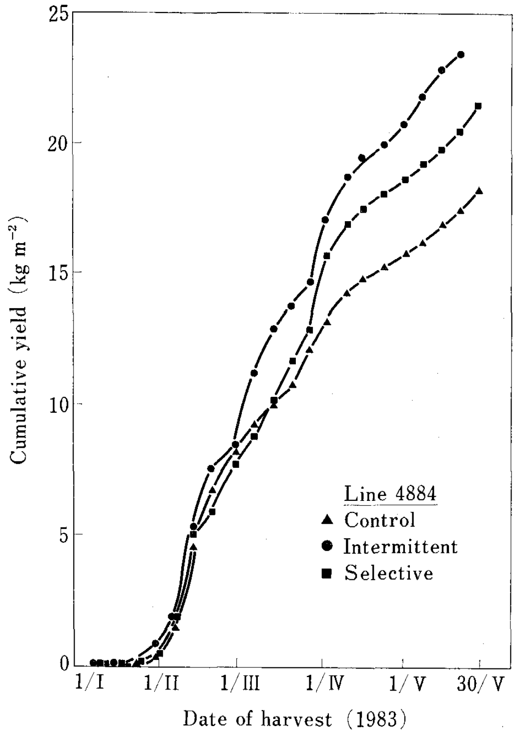

Fig. 2. Cumulative yield of tomatoes (line 4884) under different CO_2 enrichment techniques.

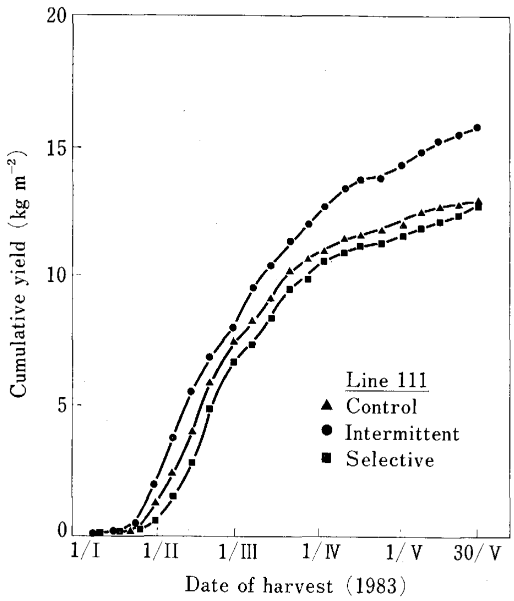

Fig. 3. Cumulative yield of tomatoes (line 111) under different CO_2 enrichment techniques.

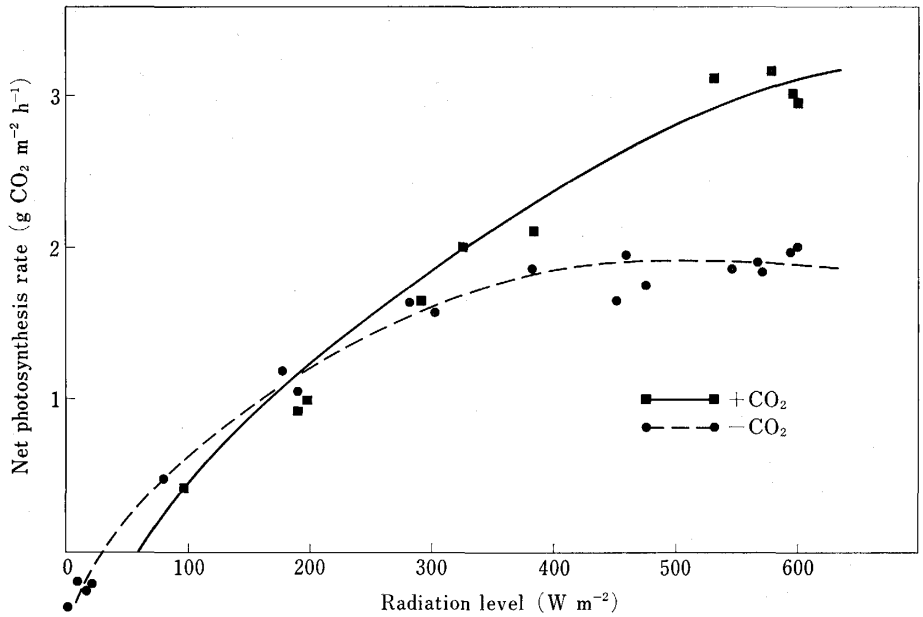

Fig. 4. The relation between radiation level and photosynthesis rate in enriched and non-enriched greenhouses (measurements made on Apr. 8. '84).

DISCUSSION

According to the results presented in Figs. 2 and 3, it is seen that intermittent enrichment has a considerable advantage over selective enrichment.

The graphic description of the enrichment techniques (Fig. 1) is an example of the enrichment regime on a typical, clear winter day. When enriching intermittently as compared with selectively, the plants were exposed to high CO_2 concentrations during a larger part of the day, including those hours when continuous enrichment was impossible because of the high radiation levels, leading to high temperatures in a closed greenhouse. From Fig. 4 it can be seen that during the hours of high radiation, also photosynthesis rates are higher and the effect of CO_2 enrichment is greater. The main advantage of the intermittent enrichment technique is attributed to this relation.

The use of intermittent enrichment requires an automatic system for control of the process in the greenhouse. In the study described herein, a relatively inexpensive and simple system was installed. The system's hardware consisted of a central computer (BMC, model IF-800), connected serially, by means of a communication cable, to end-units (Kratos Link-on, Walton Industries, Stone, Staffs., England) installed next to the electricity panels of the greenhouses. The software was written in BASIC and consisted of a series of conditions related to predetermined set-points for radiation, temperature, time, etc. The values of the set-points could be modified from the keyboard without interrupting the program. The end units served as an interface between the program and the electricity panel which contained the relays needed for operation of the various functions in the greenhouse (ventilators, fans, CO_2 valves, etc.). The scan time of the system was about 30 s, which was short enough relative to the response time of the greenhouse.

At the Besor Experiment Station experiments are carried out in order to achieve optimization of CO_2 enrichment in greenhouses, taking into account the time of day, CO_2 levels, plant age, temperature and the air exchange rate in the greenhouse. These data will enable economic improvement of the enrichment process.

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