A New System of Environmental Control for Vegetable Growing in Greenhouses

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Introduction

In recent years, a total area of greenhouses has increased rapidly in Japan, reaching 1,500 ha for glasshouses and 30,229 ha for plastic greenhouses in 1979. Of the area, 636 ha of glasshouses and 24,201 ha of plastic greenhouses are used for vegetable growing, accounting for 82.2% of the total area. Although the production of greenhouse vegetables constitutes only 11% of the total vegetable production, the percentages for fruit vegetables are very high, i.e. 39% for tomato, 35% for eggplant, 61% for pimento, 54% for cucumber, 100% for netted melon, 88% for other melon, 74% for watermelon, and 87% for strawberry. Thus, thanks to the greenhouse vegetables, consumers are able to take fresh vegetables, especially fruit vegetables, even in the winter season.

Environmental control in greenhouses

When the greenhouses are kept closed in fine days, the inside temperature goes up very high even in the winter, so that ventilation is made by shifting covering materials, opening top and side windows, or operating ventilating fans. In the night, covering materials and windows are closed, and, in addition, thermal screens are spread inside, or plastic tunnels covered by heat-insulating materials are constructed to cover crops with the purpose of protecting crops from low-temperature injury. Even so, the plant temperature lowers during the coldest season, so that heating is needed. In 1979, area of heated greenhouses was 557 ha for glasshouses, and 9,377 ha for plastic houses, representing 87.6% and 38.7% respectively of each total area. Hot-water heating is popular for the former, and hot-air heating for the latter.

In addition, CO_2-gas generators are employed in some cases. In closed greenhouses, CO_2 concentration in the air is high in the night due to crop respiration, but it decreases to 200–100 ppm, i.e. lower than atmospheric CO_2 concentration, due to photosynthesis started with sunrise. Under this condition, the low CO_2 concentration greatly limits photosynthesis, although light intensity and temperature are sufficient. To promote the photosynthesis, CO_2 is enriched during a period of several hours from the sun rise to the beginning of ventilation. At present, the supply of CO_2 is practiced for melon (netted), cucumber, and tomato in greenhouses.

Control of individual or combined environmental factors

To control greenhouse environment, control of individual environmental factors has been practiced so far. For example, in temperature management, ventilating fan and opening or closing of top- and side-windows are operated by thermostat in daytime while heater is operated by time switch and thermostat when air temperature in greenhouse lowered to a set level. CO_2 generator is also operated for a certain period by time switch.

This method, however, results in the setting of temperature or CO_2 concentration as independent of weather. In cloudy, rainy, or snowy days, it causes unnatural conditions

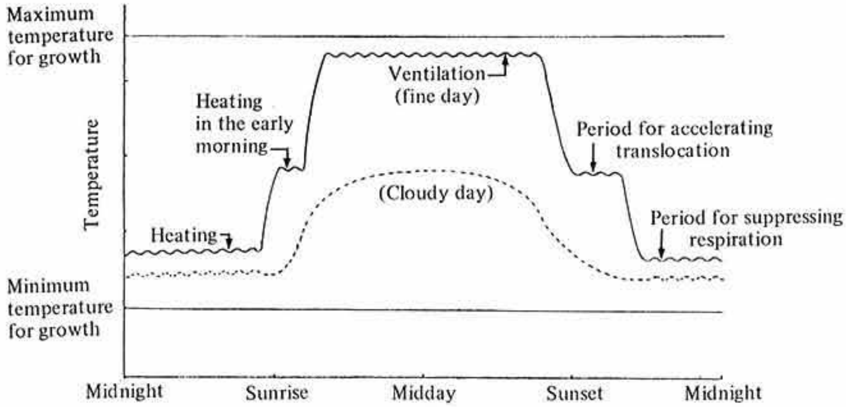

Fig. 1. Temperature control in the greenhouse

such as night temperature higher than day temperature, although causing less problems in fine days. When such an unnatural condition lasts for 1 week, plant growth is extremely inhibited due to an excessive respiratory loss. Supply of CO_2 under bad weather is also useless, because of low photosynthesis.

Thus, the environmental control based on plant physiology, namely the whole system of photosynthesis—translocation of photosynthate—respiration—dry matter production, is considered to be rational. As given in Fig. 1, photosynthesis starts with sunrise, but it is not performed sufficiently due to low air temperature in greenhouse at that time. Therefore, heating for 1–2 hr before the sunrise to warm up the air temperature is practiced in some cases, and called "early morning heating". Furthermore, CO_2 generator is operated to supply CO_2 at the time when CO_2 concentration lowered after 30 min–1 hr from the sunrise, as stated above.

The air temperature becomes high after several hr from the sunrise, when greenhouses are kept closed, so that ventilation is made. The high temperature reduces photosynthetic efficiency and exerts an adverse effect on flower-buds. In the evening, the ventilation is ceased and greenhouse is closed, but inside air temperature lowers rapidly due to lowering outside air temperature. It was usual in the past to operate heater when the night temperature lowered to a certain level. However, recently becoming popular is the "varying night-temperature management", in which night time is divided into the early half (several hr after sunset) and the later half (from the end of the early half to sunrise), and the former is kept at a relatively high temperature while the latter at a lower temperature.

The reason is that the translocation of photosynthate produced in leaves is carried out in daytime and continues after sunset. A study by the use of radio-isotope showed about 2/3 of the photosynthate produced in a day is translocated in the daytime and remaining 1/3 in the night time. Relatively high temperatures 13–18C°, are suitable for the translocation, while at low temperatures the photosynthate remains in leaves, being not completely translocated, and it gives adverse effect on photosynthesis in the succeeding day. In the varying night temperature management, the relatively high temperature in the early half of night time accelerates translocation, and relatively low temperature in the later half serves to prevent respiratory loss.

The above description is for fine days. In case of cloudy, rainy, or snowy days, the early morning heating or CO_2 supply is less effective in promoting photosynthesis, unless sup-

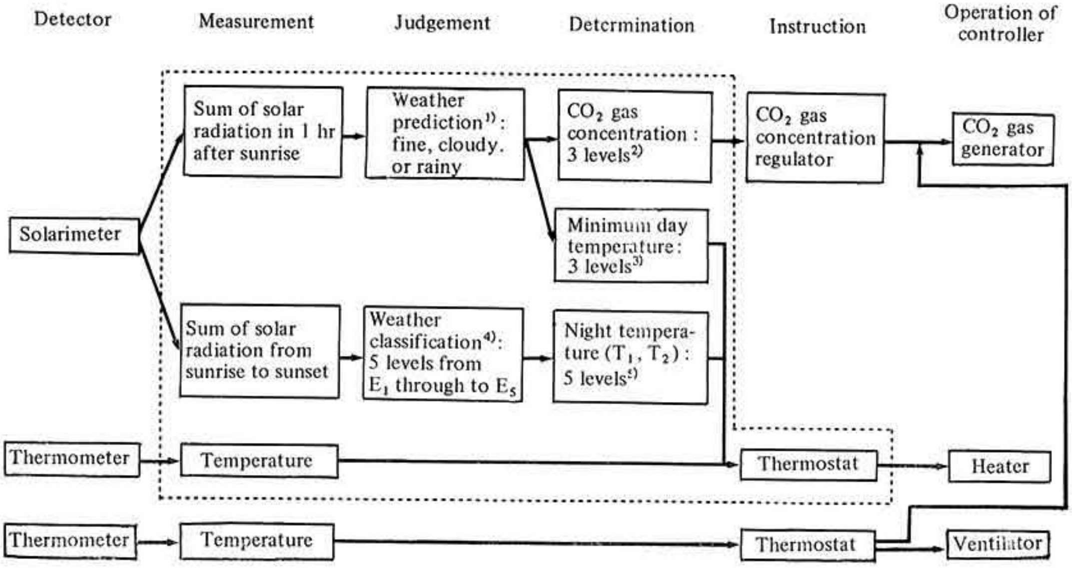

Fig. 2. Outline of the new system to control combined environmental factors

1): Weather prediction based on sum of solar radiation in 1 hr after sunrise: 0–1.4 *ly* as rainy, 1.5–2.6 *ly* as cloudy, and 2.7 *ly* < as fine.

2): Based on weather prediction, concentration of CO_2 to be supplied is determined at 3 levels

3): Similarly, minimum day temperature to be set is determined at 3 levels

4): Based on the total solar radiation for a whole day, the weather of the day is classified into 5 levels: 0–74 *ly* as E_1, 75–149 *ly* as E_2, 150–224 *ly* as E_3, 225–299 *ly* as E_4, and 300 *ly* < as E_5

5): Night temperature (T_1, T_2) to be set is determined in response to 5 levels of E

T_1: Temperature of the period for accelerating translocation

T_2: Temperature of the period for suppressing respiration

plemental light is provided, due to reduced solar radiation in these days. Also, because of less amount of photosynthate produced, high temperature treatment in the early half of night time aiming at promoting the translocation is not necessary.

Thus, it is desirable to have a system which can control temperature and CO_2 concentration according to the weather of each day. As the system controls more than two environmental factors in combination it is named the system to control combined environmental factors.

A new system to control greenhouse environment

The control system newly devised by the author and his co-workers is the one developed on the basis of plant physiology, i.e. photosynthesis and matter production. The system has the following characteristics, and is presupposed to be applicable to greenhouses.

The outline of the system is shown in Fig. 2. The feature of this system is that it can predict the weather of a day by measuring a total solar radiation received in 1 hr after sunrise, and determines CO_2 concentration and minimum day temperature to be set in accordance with the predicted weather of the day. Namely, it intends to promote photosynthesis by raising CO_2 concentration and air temperature in fine days. Thus, the control is made based on the weather prediction. When the weather changes later, it results in mis-prediction. However, this system was adopted by considering that there will be no big errors, because (1) the CO_2 supply is practiced during the winter, and in the Pacific side of Japan, where greenhouse cultivation prevails in that season, the weather in winter is relatively stable with plenty of fine days, and (2) the CO_2 supply is limited only for several hours from sunrise to the time of ventilation. The duration of CO_2 supply is set by a time switch but it ceases with the start of ventilation when the temperature rises to a set level.

The second feature of this system is that night temperature varies depending on accumulated solar radiation, taken as a substitute for measuring photosynthesis which is technically difficult. Several hours from evening to midnight is defined as the period for accelerating translocation, and the temperature during this period is kept high to promote the translocation from leaves to fruit for the days with plenty of solar radiation, but it is kept low for the days with a little solar radiation. Night time after this period is regarded as the period for suppressing respiration, and temperature is kept lower by several degrees.

Effectiveness of the new system

Effectiveness of this new control system was examined with glasshouse tomato cultivation in 1977 and 1978. The result of 1977 showed that the new system (the minimum night temperature: 18~10°C in early half and 13~5°C in later half depending on accumulated solar radiation, and CO_2 concentration, 1,000 and 500 ppm for fine and cloudy days, respectively, and no CO_2 supply in rainy days) increased the total dry matter by 14% and fruit yield by 25% that of the former system to control individual factors (the minimum temperature 8°C, and no CO_2 supply). This effectiveness was more remarkable in the plots where young seedlings were planted, and with high soil moisture (Fig. 3). In 1978, five cultivars were used for the experi-

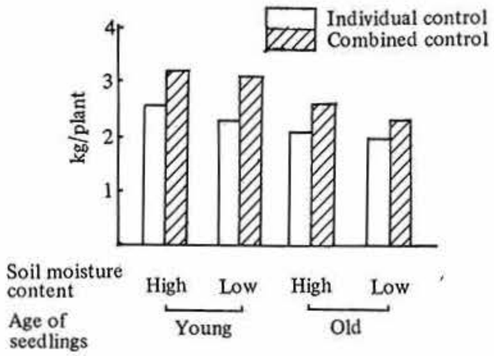

Fig. 3. Yield of greenhouse tomato grown under the control of individual or combined environmental factors

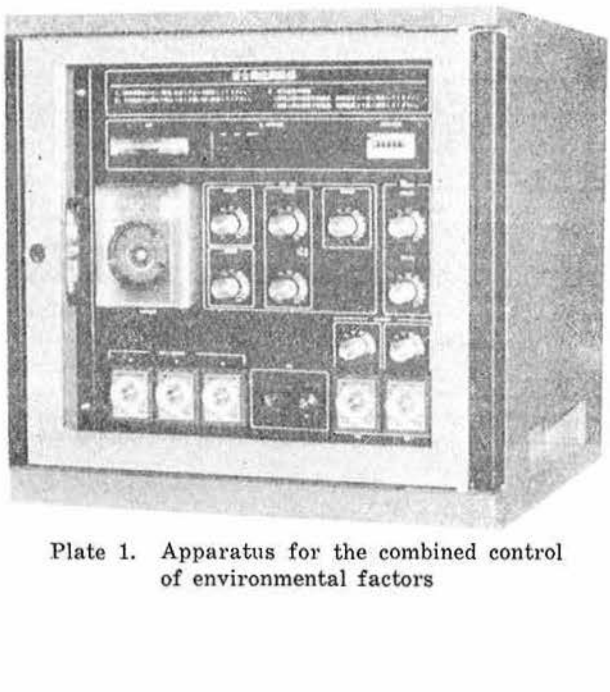

Plate 1. Apparatus for the combined control of environmental factors

ment, and the yield increase of 30% was obtained by the new system (minimum night temperature in early half 18～10°C, in later half 8°C, CO_2 concentration, 1,000 ppm for fine days, 500 ppm for cloudy days, and no CO_2 supply in rainy days) as compared to the former system (minimum night temperature, 10°C, and no CO_2 supply).

Based on these results it can be expected to get yield increases not only with tomato, but also with other fruit vegetables by the use of the combined control system. In addition, the use of varying night temperature can eliminate useless heating, resulting in saving fuel consumption.

As already mentioned, this new facility was developed, anticipating its practical use for greenhouses. Therefore, the combined control can be made possible only by introducing this facility (Plate 1) and necessary detectors to the greenhouses already equipped with heater or heating facility, fan or automatic opening and closing of top- and side-windows, and CO_2 gas generator.

This system was adopted in the energy-saving (combined environmental control type) model areas, initiated by Ministry of Agriculture, Forestry, and Fisheries in 1979, and its effectiveness was proved actually.

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(Received for publication, June 29, 1982)