A Use of TGC (Temperature Gradient Chamber) to Evaluate Crop Growth Responses to Temperature

Masumi Okada, Takahiro Hamasaki and Takami Hayashi

ABSTRACT

A simple and low-cost temperature gradient chamber (TGC) has been developed by providing a continuous one-way air flow in a long tube greenhouse. Temperature of the incoming air is close to outdoor temperature and rises gradually with a distance from the inlet by sensible heat gain from solar radiation or supplementary heating cables. A gradient of air temperature is thus observed along a long axis of the greenhouse. In our 18 m long TGC monthly mean temperature differences between the air inlet and the outlet resulted in 2-3 °C during summer crop seasons. Rice and soybean were planted along the gradient and shift planting technique was introduced at intervals of 3-4 weeks. A linear dependence of the developmental rate on temperature was observed from the results of each planting and the responses to a wider range of temperature or different daylength were obtained from those of shift planting. The data necessary to model the effects of cool temperature on floral damage and the subsequent dry matter production were also obtained more efficiently in the TGC experiment than in the outdoor one. A deviation of an air-soil temperature relation was observed in the TGC, which seemed to affect crop growth as a chamber effect.

INTRODUCTION

An idea of a temperature gradient chamber was first proposed by Mihara (1971) in his TRC (Temperature Response Curve) technique to separate the effects of temperature on plants from those of other environmental factors. His TGC was a 50 cm high plastic tube tunnel with an air inlet at one end and an exhaust fan at the other end. Under continuous ventilation a temperature gradient was created along the air flow direction in the daytime and a magnitude of the gradient depended on solar heat gain. It was only recent that this simple idea of the chamber was recognized as an effective tool to evaluate crop-temperature relations (Okada, et al., 1992, Nakagawa, et al., 1992). The TGCs developed by the authors are constructed with a commercial greenhouse materials, and are equipped with heating cables and control facilities so as to obtain a certain gradient under a small heat gain such as in the nighttime or in a cloudy day. The present study will discuss the effectiveness of TGC as a growth data acquisition tool as well as specific chamber environment deviating from outdoors.

TGC IN TNAES

For field crop experiment a larger chamber than Mihara's one is required. The gradient in a large chamber, however, often becomes very small. This is because recirculating eddies created by buoyancy produces an apparent back flow and stirs inside air. To reduce this inexpedient air stirring, an air inlet and flow rate control is improved in our TGC. Figure 1 represents schematically the framework of the TGC. The TGC is basically a commercial greenhouse of pipe structure covered with PVC film; 3.6 m in width, 2 m in height and 18 m in length. The air inlet is covered with a perforated board to regulate incoming air flow. Each hole is 10.5 mm in diameter and evenly distributed in 3 cm grid on the board. A hole is added in the center of the grid in the upper half of the board. The incoming air, thus, flows more smoothly in the upper section than in the lower. Three exhaust fans, each of which has a ventilation rate of 28 m^3/min, are installed at the other end. Two fans are always operated while one is operated only when temperature difference between 16 m and 1 m from the air inlet is larger than 3 °C; namely a gradient of 0.2 °C/m. An average sectional air flow velocity is 0.3 m/s when 3 fans are operated. Electric heating cables are distributed by the side walls. Totally 3 kw are supplied when the 16 m - 1 m temperature difference is smaller than 2 °C; a gradient of 0.13 °C/m.

TEMPERATURE GRADIENT

Control devices and algorithm are so simple that a temperature gradient depends to a considerable extent on both solar heat gain and wetness inside the chamber. Figure 2 shows a daily course of the air temperature difference between the specific location in the chamber and the outdoor in a typical clear day. As these data were taken under low leaf area and dry soil conditions, the gradient exceeded 0.5 °C/m around midday. In this context the air flow rate of our TGC was insufficiently small to avoid an extremely high temperature near the air outlet. Such an large gradient was, however, easily reduced by irrigation on soil surface and was seldom observed when leaf area became large. As shown in Fig. 3, monthly mean temperature difference between the air inlet and the outlet resulted in 2-3 °C during summer crop seasons.

The lines between 0 m and 1 m from the air inlet drawn in Fig. 3 did not indicate the reality, since air temperature very close to the air inlet was usually much closer to one measured at 1m. Namely the incoming air temperature jumped up after passing through the inlet. Figure 4 compares the rise of temperature across the chamber under 1 fan and 3 fan operation. The temperature jump was more remarkable when an air flow rate was small. The cause of the jump might be an apparent back flow created by buoyancy. Vertical profiles of air flow velocity and temperature between plant rows are shown in Fig. 5. Under a small temperature gradient the profiles were fairly uniform, while air flow velocity decreased and air temperature increased with a height above the ground under a large gradient. This suggests that an upper air layer tends to flow backward when a gradient is large and air flow velocity is not large enough to break a back flow. A small air flow rate, therefore, possibly fails to increase a gradient. From these results the control algorithm described in the previous section was determined.

EXAMPLES OF CROP RESPONSES

Growth processes focussed in this study are; 1) phase development influenced by photoperiod and temperature and 2) cool temperature damage on fertility and resultant dry matter production. As temperature regime in the TGC is essentially under the influence of outdoor temperature, growing plants in different seasons is an effective way to obtain growth responses to a wide range of temperature. Shift planting by sowing at intervals of 3-4 week was introduced in the present experiments.

Phase development

Figures 6 and 7 correlate developmental rates of rice and soybean plants to mean air temperature. A developmental rate is defined as an inverse of the number of days from emergence to heading for rice and to flowering for soybean. A small cluster of the symbols corresponds to each crop of shift planting and each symbol designates one pot placed along the gradient. Some open field data are also plotted in case of rice. The developmental rate in the same cluster seemed to relate linearly to the mean air temperature, but the relations throughout all the different clusters varied with every cultivar or species. For a low photo-sensitive rice cultivar *Akihikari*, a curvilinear relation between the developmental rate and the mean air temperature was observed in a wide range of temperature. The responses of a high photo-sensitive rice cultivar *Koshihikari* was more complex. A photoperiod varying with every planting apparently affected the developmental rate and caused a scatter of clusters. As long as temperature responses are concerned, the developmental rates of both early and late planting seems to depend more largely on temperature than those of middle planting. The similar trends were more remarkably observed for a soybean cultivar *Enrei*. Such interesting results cannot be obtained from a usual open field experiment even though shift planting is introduced. It should be noted that the open field data were aligned along an extension of the corresponding TGC data in Fig. 6. This suggests that specific chamber environment discussed later is less influential in phase development - temperature relations.

Cool summer temperature damage

Cool summer temperature is the largest factor to fluctuate crop yield in northern Japan. A degree of floral fertility is easily regulated by exposing plants to autumn cool in case of a TGC experiment. Figure 8 shows the relationship between a harvest index of rice plants and mean air temperature during a sensitive stage. The harvest index is given by dividing a panicle dry weight by a total dry weight. Since the floral stage sensitive to cool temperature is from panicle initiation to flowering, the mean air temperature from 20 days before and 10 days after heading is simply used as an independent variable. Two crop data from shift planting are plotted in the figure. The earlier crop was less exposed to a critical cool temperature, while the later one was to a certain degree depending on the pot location in the chamber. A linear decline of the harvest index was observed below 21 °C. The corresponding dry weights are represented in Fig. 9. An interesting trend was observed in the partial weight. The decrease of panicle weight did not affect a total weight which was compensated by the increase of shoot and root weights. These results are helpful to model the effects of cool temperature on floral damage and the resultant dry matter production.

REMARKS ON SPECIFIC CHAMBER ENVIRONMENT

How close the environment in an artificial chamber is to natural one is a common question for chamber researchers. The factors other than air temperature often becomes unknown in case of a TGC. The reduction of light is inevitable and is usually by 30-35%. A decrease of carbon dioxide and a change of vapor pressure deficit are an another factor influential in crop growth, which was well discussed by Mihara (1971). It is even possible to provide a gradient of carbon dioxide concentration by injection in the chamber. Since there is trade-off between air temperature and vapor pressure deficit, it is rather difficult to control simultaneously those two factors.

In this paper the authors would like to emphasize an air-soil temperature relation as specific chamber environment, which has not been discussed sufficiently. An air-soil temperature relation depends not only on solar radiation but also on longwave radiation and convective heat exchanged on soil surface. Those factors are all modified under cover. Daily mean soil temperature measured at a depth of 5 cm are plotted against daily mean air temperature in Fig. 10. Since the data were collected from the second day of the consecutive two clear days, the influence of a phase delay of soil temperature was small on comparing daily averages of soil and air temperature. The soil was filled with water like paddy and no crop was planted. As clearly shown in Fig. 10, the difference between soil and air temperature was approximately 2 °C larger in the TGC than outdoors. To explain this deviation energy balance was calculated on soil temperature. Figure 11 represents how large extent each factor contributes to the deviation of an air-soil relation in the chamber. As the calculation was performed for completely dry soil, the soil minus air temperature difference was much larger than that in the experiment for paddy soil. Covering materials of a chamber transmitting 70% of solar radiation decreased soil temperature by 3 °C when compared with open field. On the other hand the materials opaque to longwave radiation reduced considerably heat loss from soil surface and thus increased the temperature by 6 °C. Reduction in convective heat transfer in a chamber caused another increase of 6 °C. The combination of these effects brought totally 10 °C higher soil temperature in a chamber than outdoors in case of dry soil. Wetness of soil surface may reduce significantly this deviation, but the increase of soil temperature appears to be inevitable in an enclosure like a TGC. The so-called 'chamber effects' will be significant when crop responses sensitive to soil temperature are concerned such as seed germination, water uptake and its resultant effect on elongation.

REFERENCES

Mihara, Y., 1971 : Proposing temperature response curve technique for field crop experiment. *Agriculture and Horticulture*, 46, 721-726 (in Japanese).

Nakagawa, H., Horie, T., Nakano, J., Kim, H.Y., Wada, K. and Kobayashi, M., 1992 : Effects of elevated CO_2 concentration and high temperature on the growth and development of rice. *J. Agr. Met.*, 48 (5: special issue), 799-802.

Okada, M., Ozawa, K. and Hamasaki, T., 1992 : A use of TRC technique for an analysis of crop responses to temperature. *Agr. Met. Tohoku*, 37, 23-25 (in Japanese).

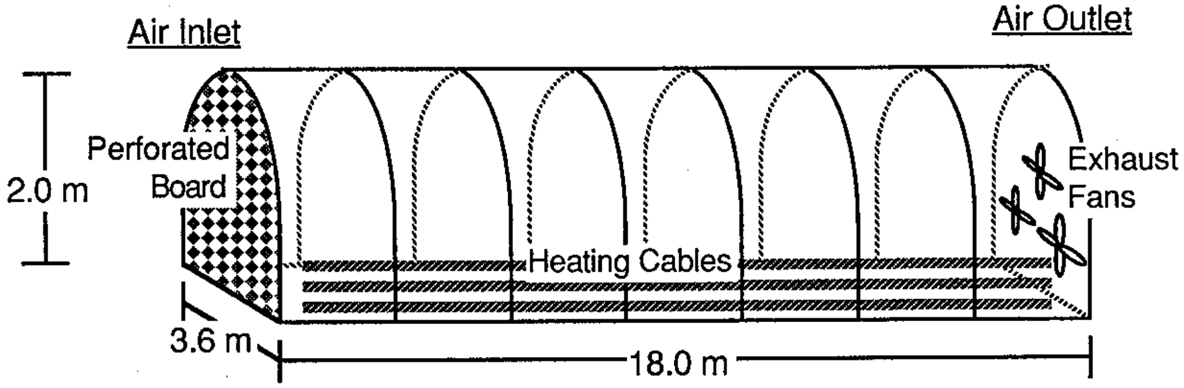

Fig. 1 Schematic drawing of TGC in TNAES.

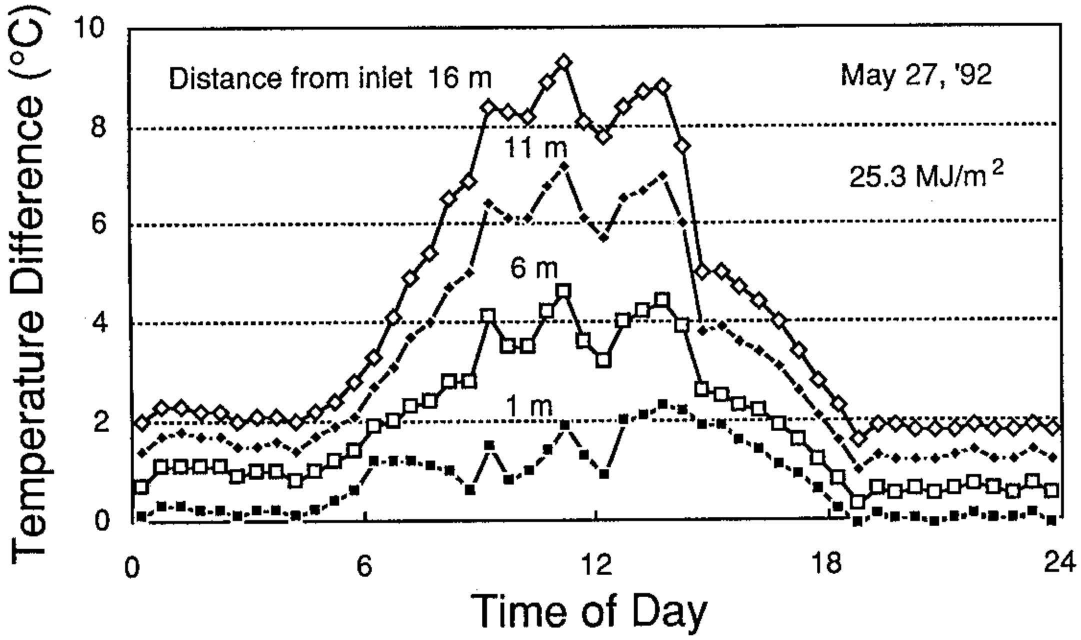

Fig. 2 Daily course of temperature difference between inside and outside air in a typical clear day.

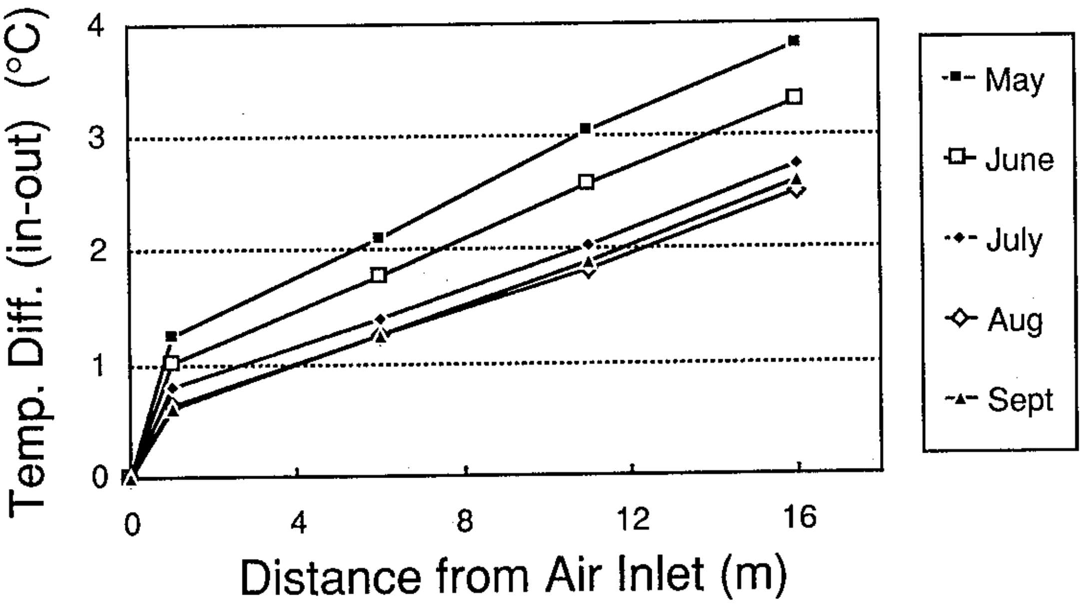

Fig. 3 Monthly mean air temperature gradient inside the TGC. Vertical axis is expressed as a temperature difference between inside and outside air.

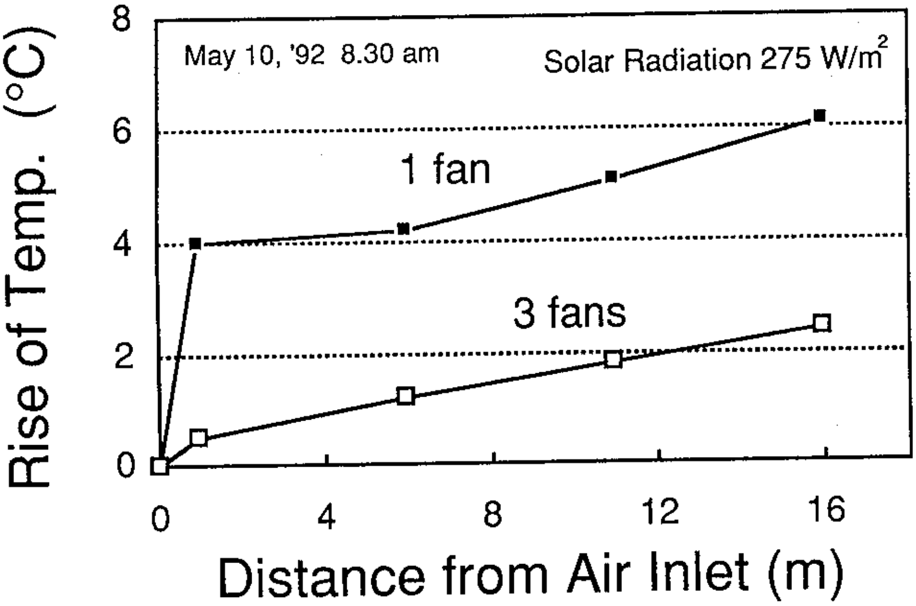

Fig. 4 Comparison of a temperature gradient under 1 fan and 3 fan operation.

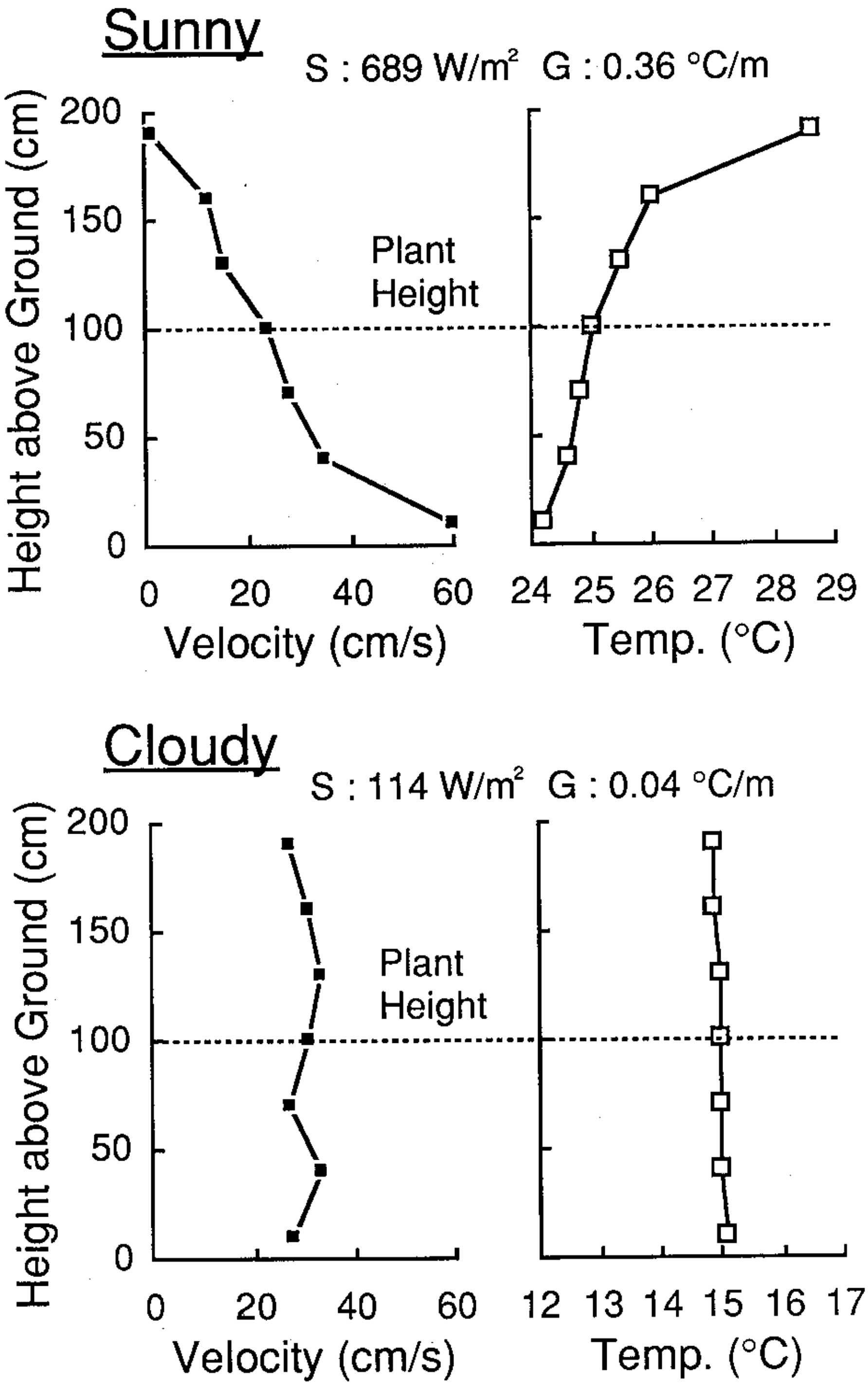

Fig. 5 Profiles of air flow velocity and air temperature.
S : solar radiation, G : temperature gradient

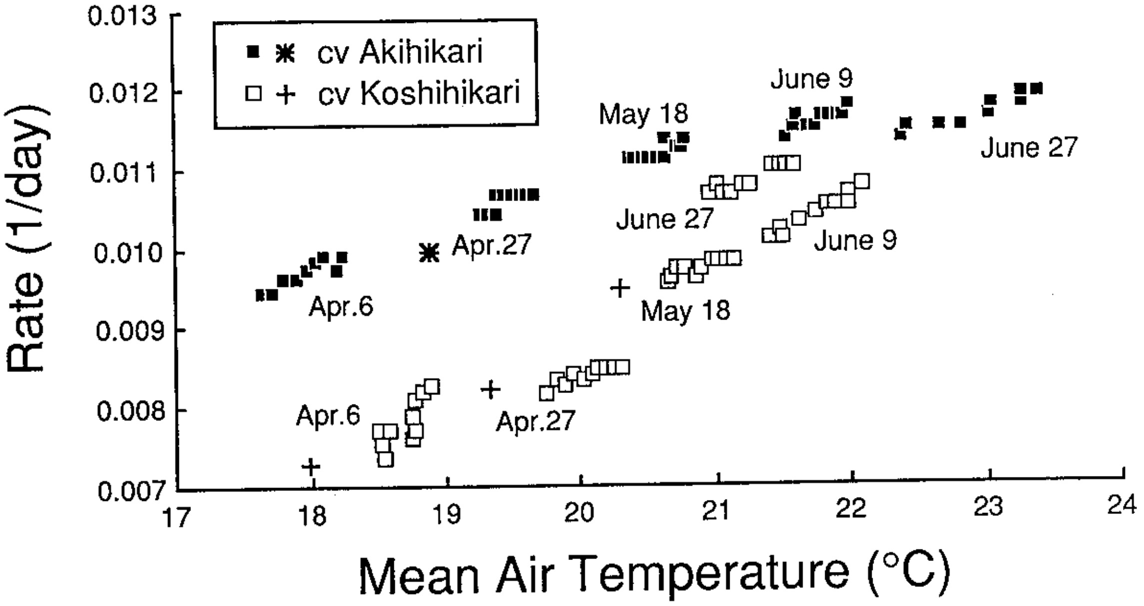

Fig. 6 Dependence of developmental rate of 2 rice cultivars on mean air temperature. Letters close to symbols denote the date of emergence. Rectangles : TGC data, Crosses : open field data

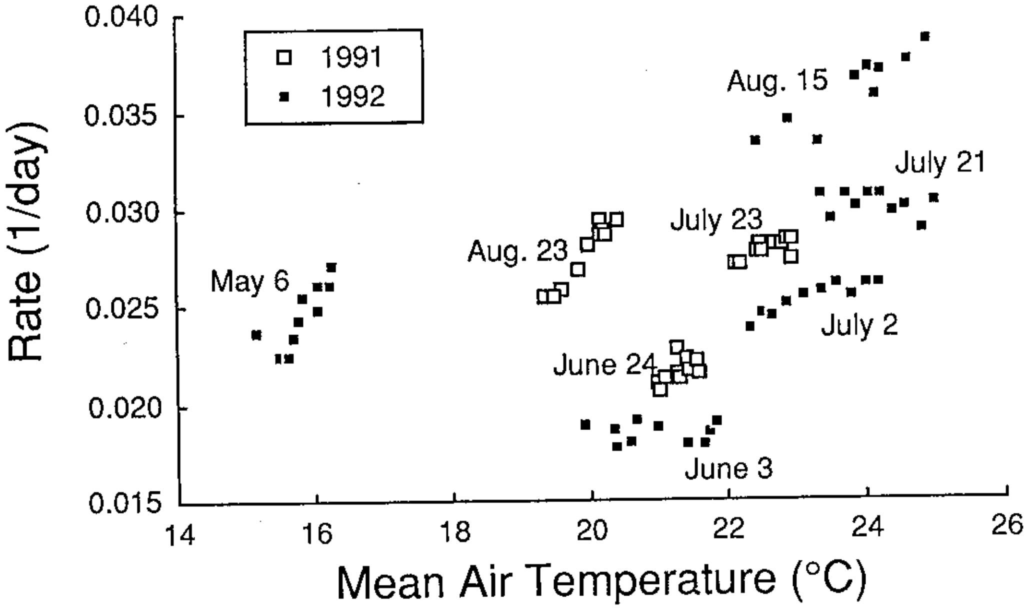

Fig. 7 Dependence of developmental rate of soybean cultivar *Enrei* on mean air temperature. Two year experimental data are plotted. Letters close to symbols denote the date of emergence.

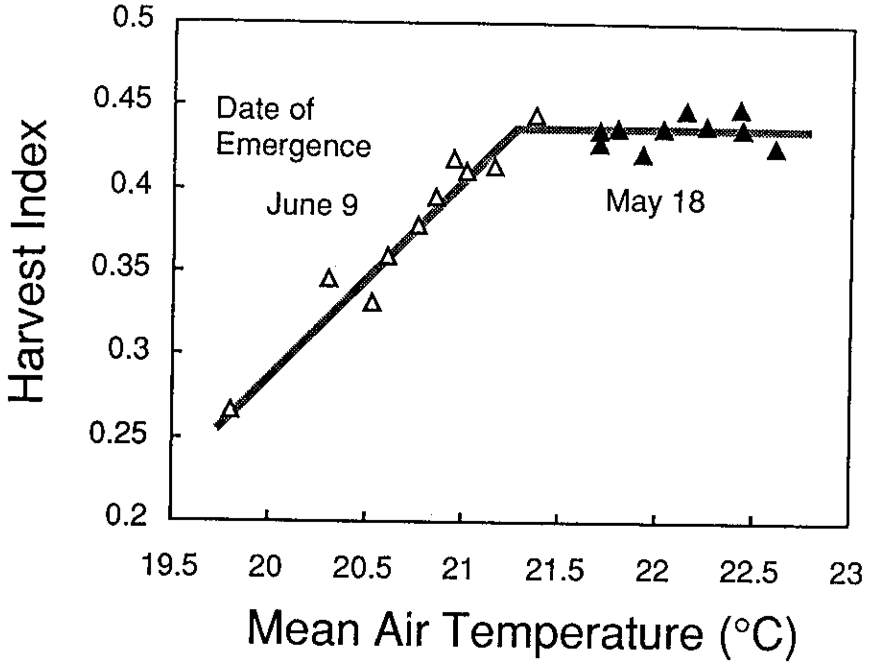

Fig. 8 Dependence of harvest index on mean air temperature from 20 days before to 10 days after heading.

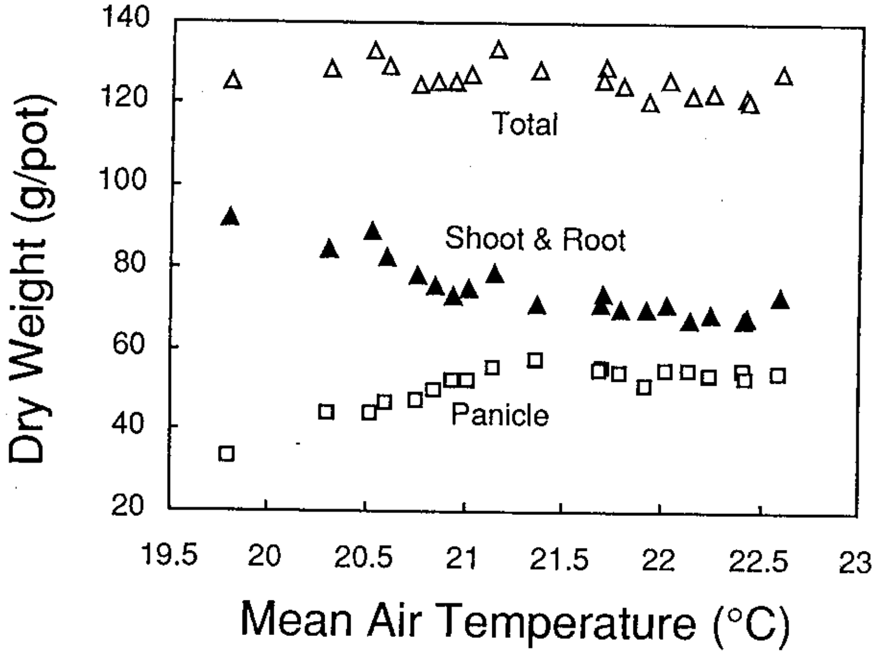

Fig. 9 Dependence of partial dry weight at time of harvest on mean air temperature from 20 days before to 10 days after heading

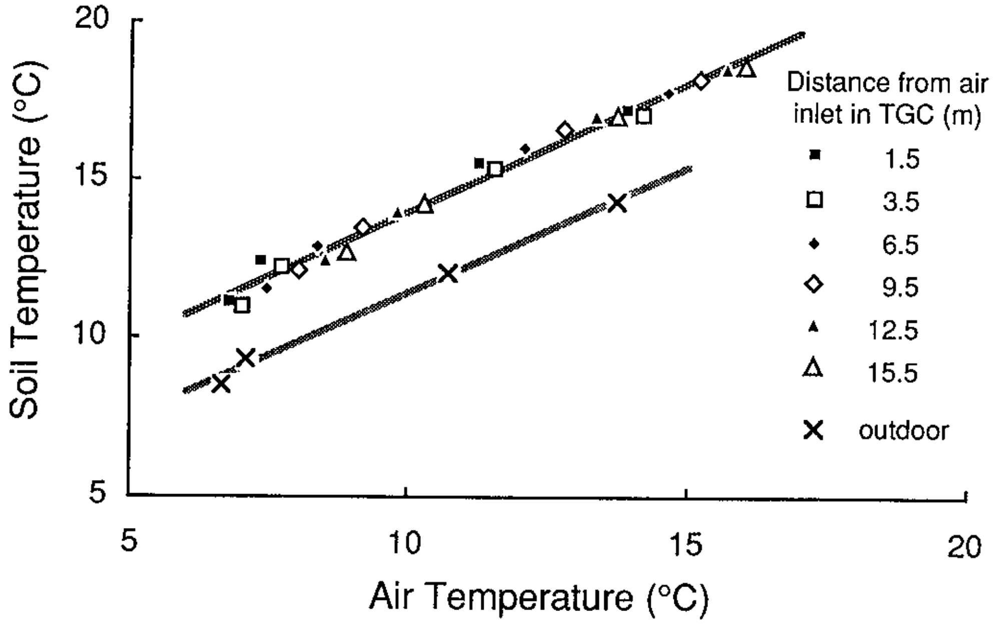

Fig. 10 Relationship of soil and air temperature in a TGC and outdoors.

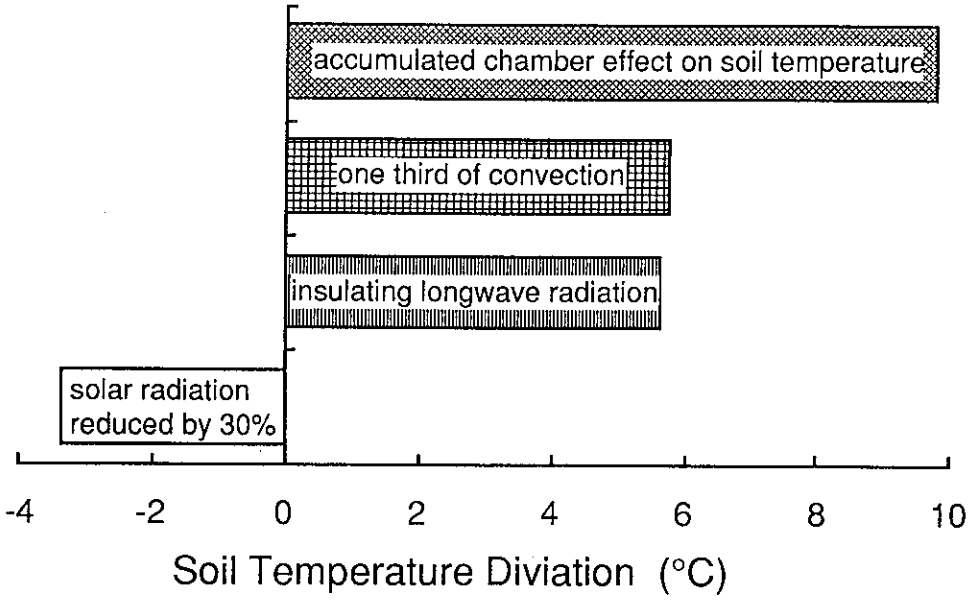

Fig. 11 Simulated contributions of chamber environment to the difference in a soil-air temperature relation between in a TGC and outdoors.