TEMPERATURE GRADIENT CHAMBERS FOR RESEARCH ON GLOBAL ENVIRONMENT CHANGE : II. DESIGN FOR PLOT STUDIES

Sinclair, T. R.
Agronomy Physiology Laboratory University of Florida Gainesville

Allen, L. H.
Agronomy Physiology Laboratory University of Florida Gainesville

Drake, G. M.
Agronomy Physiology Laboratory University of Florida Gainesville

https://hdl.handle.net/2324/8213

出版情報：BIOTRONICS. 24, pp.99-108, 1995-12. Biotron Institute, Kyushu University
バージョン：
権利関係：

TECHNICAL RERORT *BIOTRONICS* **24**, 99–108, 1995

TEMPERATURE GRADIENT CHAMBERS FOR RESEARCH ON GLOBAL ENVIRONMENT CHANGE.
II. DESIGN FOR PLOT STUDIES

T. R. SINCLAIR, L. H. ALLEN, JR., and G. M. DRAKE

USDA-ARS
Agronomy Physiology Laboratory
University of Florida
Gainesville, FL 32611-0840, USA

(Received March 20, 1995; accepted June 20, 1995)

SINCLAIR T. R., ALLEN L. H., JR. and DRAKE G. M. *Temperature gradient chambers for research on global environment change. II. design for plot studies.* BIOTRONICS **24**, 99–108, 1995. Temperature gradient chambers (TGC) offer technology to study a large number of plants grown under a range of temperatures. Heating of air flowing through the TGC results in a continuous gradient of increasing temperature. However, the existence of the continuous temperature gradient makes the establishment of specific temperature treatments and the interpretation of the results difficult. A major objective of the TGC design reported in this paper was to establish individual temperature plots (5.5 m L × 4.3m W) within the TGC. These plots were obtained by installing overhead paddle fans at intervals in the TGC to define the boundaries of the temperature plots. Disruption of the natural convective backflow in the TGC by these fans and the addition of supplemental heat at these points resulted in approximate step changes in temperature at the plot boundaries. The TGC has been used to establish four temperature treatments: +0, +1.5, +3.0, +4.5℃. Approximately a 1℃ step change in temperature occurred at the plot boundaries and a 0.5℃ temperature-gradient increase occured in each plot. A CO_2 release system has also been incorporated into the TGC design. This TGC system has proven to be inexpensive to construct and reliable under long-term operation.

Key Words : temperature gradient chamber ; global environment change ; wheat.

INTRODUCTION

Large temperature gradient chambers (TGC) allow large amounts of plant material to be studied. Therefore, the TGC constructed at Gainesville, FL were of a similar size to those used by Okada *et al.* (*5*). However, three major modifications were attempted to provide an environment in the TGC somewhat different than achieved by Okada *et al.* (*5*). These modifications were made (a) to achieve greater stability in the temperature gradient in the

TGC, (b) to approximate temperature zones in the TGC more consistent with plot experiments, and (c) to allow enhancement of atmospheric carbon dioxide concentrations. An important over–riding consideration in the design of the TGC was to minimize cost and complexity.

The basic construction of the TGC was a free–standing greenhouse. A variable–speed fan was placed at the exhaust end, or warm end of the TGC, and regulated to maintain an approximately constant temperature difference over the length of the TGC. Paddle fans were mounted on the ceiling of the TGC at four locations to disrupt convective backflow in the TGC and to establish boundaries for four temperature plots (Fig. 1). A carbon dioxide release system was controlled in parallel with the exhaust fan speed so that elevated CO_2 could be maintained in the TGC.

CHAMBER DESIGN

Structure

The TGC was constructed using a commercial, free–standing greenhouse (Inflation Buster Greenhouse, X. S. Smith. Eatontown, NJ) covering a total soil surface area of 4.3×27.4 m. The greenhouse consisted of a series of semi–circular support bows (3.4–cm diameter pipe) anchored in the soil at a spacing of 1.8 m. A ridge pipe running perpendicular to the support bows

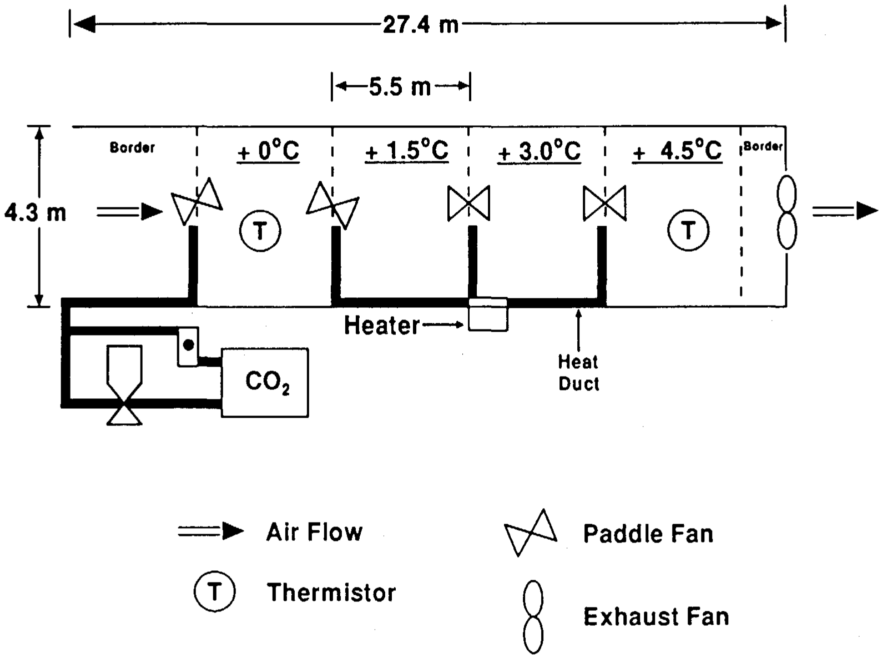

Fig. 1. Schematic top–view drawing of Temperature Gradient Chamber (TGC) developed at Gainesville, FL including the CO_2 release system for elevated atmospheric CO_2 treatment. The air flow in this schematic is from left to right and the four plots with the TGC are identified as +0, +1.5, +3.0, and +4.5℃.

anchored the bows together. A locking spline was mounted on the exterior of each bow in which the covering film of the TGC could be secured.

A 1.9-m wide polyethylene telephtalate film (Sixlight, Taiyo Kogyo Co., Tokyo) was secured between the support bows of the TGC. As discussed by Horie *et al.* (*4*), the polyethylene telephtalate film is clear and has a high transparency, including transmittance of UV radiation at wavelengths above 300 nm. The film is also rugged with an expected lifetime of 5 years.

Airflow

To control airflow in the TGC, and thereby regulate the temperature gradient, a variable speed exhaust fan (American Coolair Corp., Jacksonville, FL) was mounted at the warm end of the TGC (Fig. 1). The capacity of the exhaust fan was between 340 and 1,130 m^3 min^{-1}. At or below the set temperature difference between the two extreme plots in the TGC (usually 4.5℃), the exhaust fan was "idled" at its minimum capacity. When the temperature difference inside the TGC increased above the set difference, the exhaust fan speed was increased. In most cases, the exhaust fan was brought to full speed at 1.0℃ above the set temperature difference (*i. e.*, usually 5.5℃).

The exhaust fan speed was regulated with a commercial controller (Model TVS, Phason, Inc., Winnipeg, Canada). This controller was originally designed to operate on a set, absolute temperature measured with a thermistor. Therefore, a special comparator circuit was designed and constructed to input a temperature differential into the controller. The input to the comparator circuit was the temperature at the two ends of the TGC as measured by linearized thermistors (Model OL-701-PP, Omega Engineering Inc., Stamford, CT). The two thermistors were suspended above the plants under small radiation shields.

To disrupt the natural convective backflow that occurs in a large TGC (*5*), four 0.9-m diameter paddle fans were mounted at 5.5-m intervals on the ridge of the TGC (Fig. 1). These were positioned at boundaries between temperature plots and directed airflow down from the top of the TGC. These paddle fans were to mix the air at the boundaries of the plots and help to establish a more uniform temperature between adjacent paddle fans.

Heating

At night and under low radiation conditions, solar heating was insufficient to maintain the desired temperature difference. To provide heating under these conditions, a 40,000 BTU, gas heater (Model 8940, Hydroflame Furnace, Salt Lake City, UT) was installed to heat the air. Hot air generated in the heater was ducted for release above all paddle fans except for the one at the entrance of the TGC (Fig.1). Release of the heated air above the fans helped to quickly disperse the hot air and to establish the boundaries of the various temperature plots.

The flow of the ducted hot air to each of the three positions in the TGC was initially balanced manually to give the desired temperature increase in each of the successive plots in the TGC. The heater was activated by the temperature controller to add heat whenever the temperature gradient over the length of the TGC decreased to less than 0.5℃ of the set gradient (*i. e.*, usually at 4.0℃). The discrete nature of heater control resulted in temperature oscillations, but the overall temperature difference along the length of the TGC was maintained.

Carbon Dioxide

Carbon dioxide release was included as a feature of this TGC design. Because the dominating variable influencing maintenance of an elevated CO_2 concentration in the TGC is the volumetric flow of air through the TGC, the addition of CO_2 to the TGC atmosphere was regulated in parallel to the exhaust fan speed. Under all conditions a constant release rate of CO_2 was made above the first paddle fan in the TGC. This release rate was fixed to give the desired CO_2 concentration in the TGC when the exhaust fan was at idle speed. For maintenance of a 700 μL CO_2 L^{-1} in the TGC when the exhaust fan was at idle required the release of about 12 L CO_2 min^{-1}. This CO_2 release rate was set manually with a gas flowmeter.

At exhaust fan speeds greater than idle, additional CO_2 was released above the first paddle fan in parallel to the fixed maintenance release. The additional CO_2 release was through a variable gas valve (Skinner valve Model BP2E, Honeywell Inc., New Britain, CT) that was regulated in parallel to the exhaust fan speed by the temperature controller. The variable gas valve could release up to an additional 30 L CO_2 min^{-1} when the exhaust fan was at maximum speed.

RESULTS AND DISCUSSION

Chamber Performance

The TGC was rather inexpensive to construct with the total cost of the components being less than $5,000 (Table 1). The simple design of the TGC and the use of standard, commercially available components allowed the TGC to be readily assembled. Approximately 200 person-hours were required to assemble one of these TGCs in the field.

A three-dimensional array of thermistors was place in the TGC to examine positional differences in temperature. Five thermistors placed at 70 cm above the soil across the width of the TGC within a temperature plot agreed within 0.1℃. There was no consistent indication of temperature variation across the width of the TGC. On the other hand, thermistors placed vertically in the TGC showed increasing temperature with height under sunny conditions. The observations of vertical increases in temperature were consistent with those of Okada *et al.* (*5*) indicating sensible heating of the air and a natural convective air flow in the TGC.

The temperature difference along the longitudal axis of the TGC was of great interest. In particular, an array of thermistors was used to document

Table 1. Components required to construct Temperature Gradient Chamber used at Gainesville, FL.

Component	Model and Manufacture	Cost
Greenhouse Structure	Inflation Buster Greenhouse X. S. Smith Eatontown, NJ	$1,600
Polythylene Telephtalate Film	Sixlight Taiyo Kogyo Co. Tokyo, Japan	800
Construction & Electrical Supplies	----------------------------	400
Exhaust Fan	American Coolair Corp. Jacksonville, FL	400
Controller	Model TVS Phason, Inc. Winnipeg, Canada	300
Heater	Model 8940 Hydroflame Furnace Salt Lake City, UT	500
CO_2 Release Valve	Skinner Valve BP2E Honeywell, Inc. New Britain, CT	400
TOTAL		$4,400

the temperature differences across temperature–plot boundaries and within the plots. Absolute temperature at 1.4 m upstream of a paddle fan (T1) and temperature difference for positions at 1.4, 2.8, and 4.1 m downstream of the fan (T2, T3, T4, respectively) are presented in Fig. 2. The temperature gradient between the two positions on either side of the paddle fan (T2–T1) was about 1.0℃. The convective backflow of air and the introduction of hot air above the paddle fan were the sources of heat for this relatively large temperature increase. Within the plot between paddle fans, temperature differences (T3–T2) and (T3–T4) were usually less than 0.5℃. Consequently, the temperature gradient within a single plot was less than 1.0℃, and commonly the gradient across the plot was about 0.5℃.

The regulation of the exhaust fan speed was effective in maintaining the desired temperature difference among the four plots: +0, +1.5, +3.0 and +4.5℃. In Fig. 3 the absolute temperatures in the four plots in the TGC are plotted for a one–hour period. The temperature oscillations for the +1.5, +3.0 and +4.5℃ plots are a consequence of the heater being turned on and off. While the short–term oscillations in temperature are 2 to 3℃, the temperature gradient is maintained over the length of the TGC.

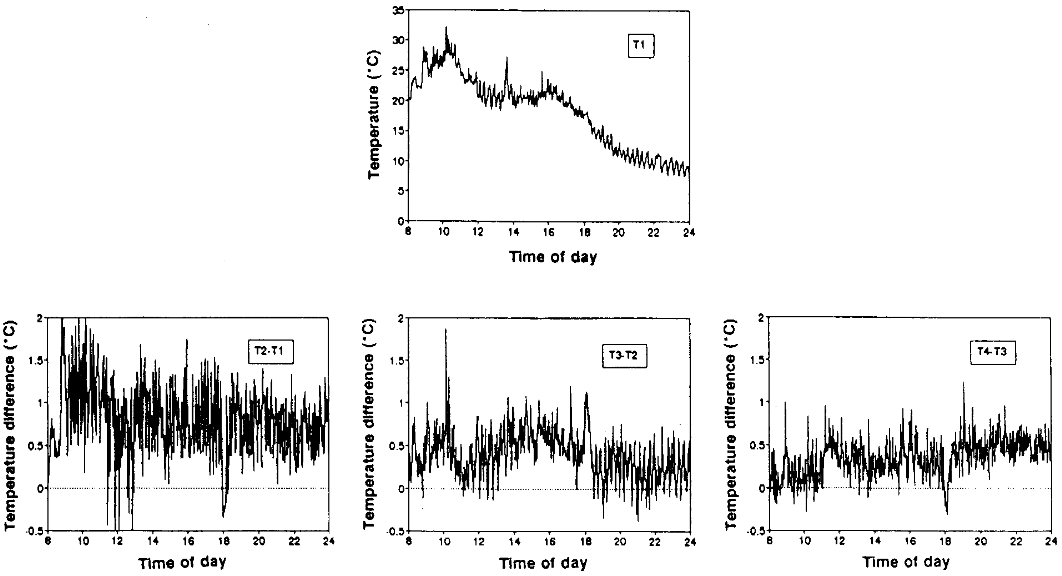

Fig. 2. Absolute temperatures at 1.4 m upstream of a paddle fan (T1) and the temperature difference at 1.4 m (T2), 2.8 m (T3), and 4.1 m (T4) downstream of a paddle fan in the TGC.

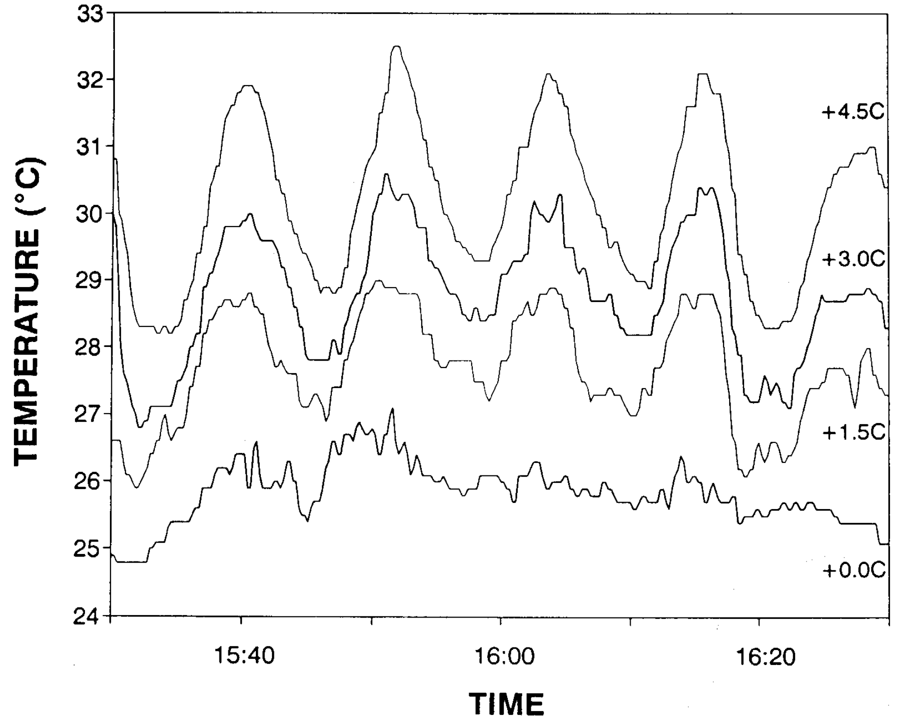

Fig. 3. Absolute temperature measurements made in a one-hour period within each of the four temperature plots (+0.0, +1.5, +3.0, and +4.5℃) in the TGC.

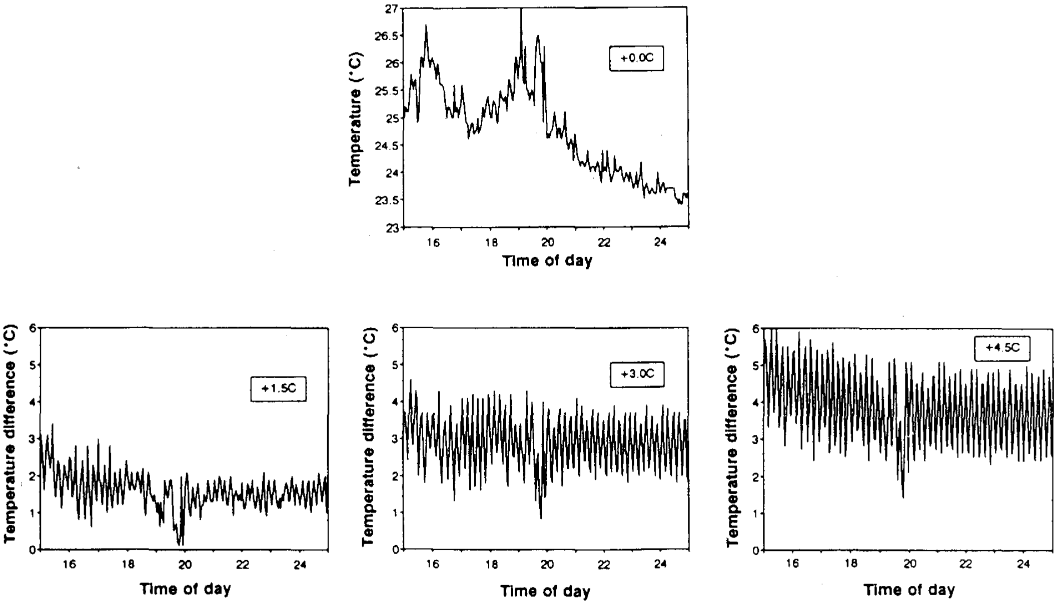

Fig. 4. Absolute temperature in the first plot in a TGC (+0.0℃) and the temperature difference for each plot (+1.5, +3.0, and +4.5℃) down the length of the TGC.

The ability of the heating system to maintain the temperature difference among plots under changing background conditions is illustrated in Fig. 4. Again the oscillations caused by the heater are apparent, but the mean difference for the plots representing temperature increases are consistent with the desired temperature differences.

Plant growth studies have been undertaken year round in the TGC and stable temperature differences were consistently maintained in the TGC. Only under the brightest conditions and with little plant cover did the temperature gradient exceed 6℃. Similarly, the heating system readily maintained the minimum temperature gradient above 3℃. Under normal conditions the temperature gradient was within ±1℃ of the 4.5℃ set temperature gradient.

The major surprise in this TGC design was the demand for heating. Certainly at night the maintenance of the demand for heat at 4.0℃ caused the heater to be reqularly cycled on. Also, during the day when conditions were overcast or there were prolonged cloudy periods, the heater would be frequently activated. Once plants had developed so that they provided substantial ground cover and intercepted most of the solar radiation, heating was commonly required intermittently throughout the day except under the highest radiation levels. This large heating requirement developed because the radiation intercepted by the well-watered plants was primarily converted to latent heat energy and the sensible heating of the air in the TGC was small. Therefore, an efficient and effective heating system was important in maintaining a stable temperature difference in this large TGC.

Crop Response

We have performed season-long studies at ambient CO_2 concentrations with wheat (*Triticum aestivum* L.) and sorghum (*Sorghum bicolor* L. Moench) grown in soil, and with rice (*Oryza sativa* L.) grown in soil vats to create a miniature paddy culture. Plant development and growth varied dramatically in response to the temperature gradient. Data are presented here from an experiment with wheat grown in a TGC from November 1992 to April 1993. Three wheat cultivars were selected for study based on potential differences in their vernalization requirements. 'Seri' was developed for warm climates so that it was anticipated to have no vernalization requirement. The cultivars 'FL303' and 'FL304' were developed in Florida and were expected to have only small vernalization requirements.

All three cultivars were sown on 20 November 1992 directly into the soil covered by the TGC. The soil was well fertilized and frequently irrigated. The temperature regime was established at sowing to give four temperature treatments of 0, +1.5, +3.0, and +4.5℃. Periodic observations on plant development were made on 12 plants from each cultivar in each of the four temperature regimes.

In Table 2 are presented observations on mean leaf number observed on 21 December and 11 January. At the time of the early observation each cultivar had produced more than four leaves. However, there was a gradient of increasing leaf number with increasing temperature on 21 December. There was approximately one more leaf produced on plants grown at +4.5℃ as compared to the 0℃ plot. While this positive response of wheat leaf development to temperature has been previously reported (*1*, *2*), previous results were less definitive because of the variability inherent in experimental results that depended on data collected over several years and locations.

Table 2. Mean leaf number and standard error (n=12) on 21 December 1992 and 11 January 1993 for three wheat cultivars grown under four temperature regimes in a TGC.

	Temperature Regime			
cultivar	0℃	+1.5℃	+3.0℃	+4.5℃
		21 Dec.		
Seri82	4.75(0.13)	5.08(0.08)	5.50(0.15)	5.67(0.17)
FL303	4.67(0.14)	5.08(0.08)	5.00(0.12)	5.42(0.15)
FL304	4.83(0.11)	4.75(0.13)	5.00(0.00)	5.92(0.08)
		11 Jan.		
Seri	8.83(0.27)	9.17(0.11)	8.55(0.24)	7.78(0.22)
FL303	8.08(0.19)	8.33(0.14)	8.42(0.15)	9.08(0.23)
FL304	7.67(0.14)	7.75(0.13)	8.42(0.15)	7.75(0.13)

Table 3. Mean development stage and standard error ($n=12$) on 11 January 1993 for three wheat cultivars grown under three temperature regimes in a TGC (1=vegetative, 2=joining, 3=booting, 4=heading).

	Temperature Regime			
cultivar	0℃	+1.5℃	+3.0℃	+4.5℃
Seri	2.00(0.00)	2.83(0.17)	3.44(0.18)	2.89(0.20)
FL303	1.75(0.13)	1.42(0.15)	1.00(0.00)	1.08(0.08)
FL304	1.00(0.00)	1.00(0.00)	1.00(0.00)	1.00(0.00)

By 11 January when leaf production had been completed in all plots, no consistent difference in leaf number was observed among the temperature plots. These data indicated that the final leaf number was not strongly dependent on the temperature regime in which the wheat cultivars were grown.

In contrast to similar responses among cultivars to temperature during the leaf-development stage, the cultivars differed markedly in their reproductive development in response to the temperature treatments. These differences were best illustrated in the developmental observations obtained on 11 January (Table 3). Seri showed an acceleration in reproductive development as temperature increased. In the +0℃ plot, the plants were only at the jointing stage, while plants in the +3.0℃ plot had advanced to a stage between booting and heading.

However, the development response of FL303 to temperature was opposite to that of Seri. The most advanced development stage on 11 January for FL 303 was in the coldest temperature plot, 0℃, where the plants were approaching the jointing stage. Increasing temperature resulted in arrested reproductive development. In the two warmest plots the plants were essentially still in vegetative development. This response is consistent with the existence of a vernalization requirement which necessitates that the plants be exposed to cool temperatures to stimulate reproductive development (*e. g., 3*). FL304 may well have had the greatest vernalization requirement of the three cultivars tested because it failed to begin reproductive development even in the +0℃ plot.

Comparison of the complex responses of wheat to increased temperature under otherwise common growth conditions, were readily facilitated in a TGC. The experimental results illustrated how the differing responses to temperature in the vegetative and reproductive stages can be identified by growing different cultivars side-by-side in a TGC.

REFERENCES

1. Baker CK, Gallagher JN & Monteith JL (1980) Daylength change and leaf appearance in winter wheat. *Plant Cell & Environment* 3, 285–287.

2. Baker JT, Pinter PJ, Reginato RJ & Kanemasu ET (1986) Effects of temperature on leaf appearance in spring and winter wheat cultivars. *Agronomy Journal* 78, 605–613.
3. Gardner FP & Barnett RD (1990) Vernalization of wheat cultivars and a triticale. *Crop Science* 30, 166–169.
4. Horie T, Nakagawa H, Nakano J, Hamotani K & Kim HY (1995) Temperature gradient chamber for research on global environment change. II. A system designed for rice in Kyoto, Japan. *Plant Cell & Environment (in press).*
5. Okada M, Hamasaki T, & Hayashi T (1995) Temperature gradient chamber for research on global environment change. I. Thermal environment of a large field chamber. *Biotronics* 24: 85–97.