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CROSS–GRADIENT GROWTH BENCH FOR THE OPTIMIZATION OF PLANT GROWTH CONDITIONS

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TISCHNER T. and VEISZ O. *Cross–gradient growth bench for the optimization of plant growth conditions.* BIOTRONICS **25**, 89–97, 1996. One of the most important criteria to be met by traditional climatic plant growth equipment is that the programmed environmental conditions should be completely homogeneous, i.e. all the experimental plants in the given phytotron unit should be exposed to identical environmental effects. In Martonvásár a plant growth unit differing fundamentally from these criteria has been produced, in which regular inhomogeneities (gradients) can be set up perpendicular to each other for two chosen environmental factors. In the gradient bench perpendicular gradients of two selected environmental factors can be programmed in such a way that a large number of combinations of the two factors will be created simultaneously in a single plant growth unit, while all the other factors are identical. As regards the methodology of the experiments, it is a further advantage that the timespan of the gradient effects can also be programmed as a third variable.

Key words: gradient chamber; growth chamber; phytotron.

INTRODUCTION

It is almost a quarter of a century now since one of the largest phytotrons in Europe was opened in Martonvásár. Since the reconstruction carried out in 1990 it is again one of the most modern in Europe, too. In the fifty plant growth and testing chambers manufactured by the Canadian firm Conviron, the climatic conditions existing anywhere in the world can be created artificially, in a programmed manner, and thus reproducibly, making it possible to carry out an exact, scientific study of the growth and development of plants.

One of the most important criteria to be met by climatic plant growth equipment is that the programmed environmental conditions should be completely homogeneous, i.e. all the experimental plants in the given phytotron unit should be exposed to identical environmental effects. In Martonvásár a plant growth unit differing fundamentally from these criteria has been produced, in which regular inhomogeneities (gradients) can be set up perpendicular to each other for two chosen environmental factors (e.g. light and temperature) (*1*). Thanks to the cross–gradient there will be a large number of combinations (around a hundred) of the two chosen environmental factors, while the other environmental parameters are identical. Each plant on the gradient bench thus grows and develops at a different value of the two chosen environmental factors, which can be easily and precisely determined. If the gradient values are wisely chosen, a single experiment may be sufficient to determine the optimum growth conditions. By repeating the experiment using a smaller gradient the area around the optimum can be magnified. If this magnification is continued the precision of the experimental conditions can be refined to an almost unlimited extent. Another important aspect of the gradient bench is that, if the gradient values are set to zero, it can be used as a traditional plant growth unit.

The cross-gradient growth bench has been patented in Canada (Patent No. 1062010/1979), Germany (No. 2639857/1986), Hungary (No. 180836/1979), Japan (No. 1315363/1986) and the USA (No. 4091566/1978) (*2*).

CHAMBER DESIGN

History

As early as 1973, the year after the phytotron was opened, we decided to try and create a plant growth unit in which a cross-gradient could be set up for two chosen environmental factors. The simplest way of doing this was to place the light canopy of a Conviron GB-48 growth bench at various angles from the horizontal (Fig. 1), so that an irradiation (illumination) intensity gradient was created at the plant growth surface. In a direction perpendicular to this gradient, fluorescent tubes with different spectra were combined to produce a gradient as regards the red light range, while the blue range remained quasi-constant. Plants growing under a light canopy constructed in this manner were each subjected to a different irradiation intensity and spectral energy distribution during growth and development. At the end of the experiment the quantitative characteristics of the plants (e.g. plant height, grain number, etc.) could be illustrated in a surface distribution (*3*).

In a further experiment, the site of the optimum could be enlarged by reducing the extent of the gradient. In the present case the extent of the gradient could be decreased by reducing the angle which the light canopy made with the horizontal. As the result of this experiment we were able to determine the fluorescent tube combination (Cool-White and Gro-Lux/WS 1:1) which has since been used in traditional phytotron units to obtain plants with a growth habit as near as possible to that observed in nature.

It was much more important, but also much more difficult, to solve the problem of creating a temperature gradient. In our first attempt, in 1975, a GB-48 growth bench was again converted. An evaporator was constructed with lamellas directly below the growth surface, or unifloor. The closeness of the lamellas changed from the front to the back of the growth bench. This evaporator was part of a refrigerating unit independent of the GB-48 and was designed to provide a secondary cooling system to create a temperature gradient in the original unit. The gradient was produced by the differing closeness of the lamellas (Fig. 2). Unfortunately, it did not prove possible to create a

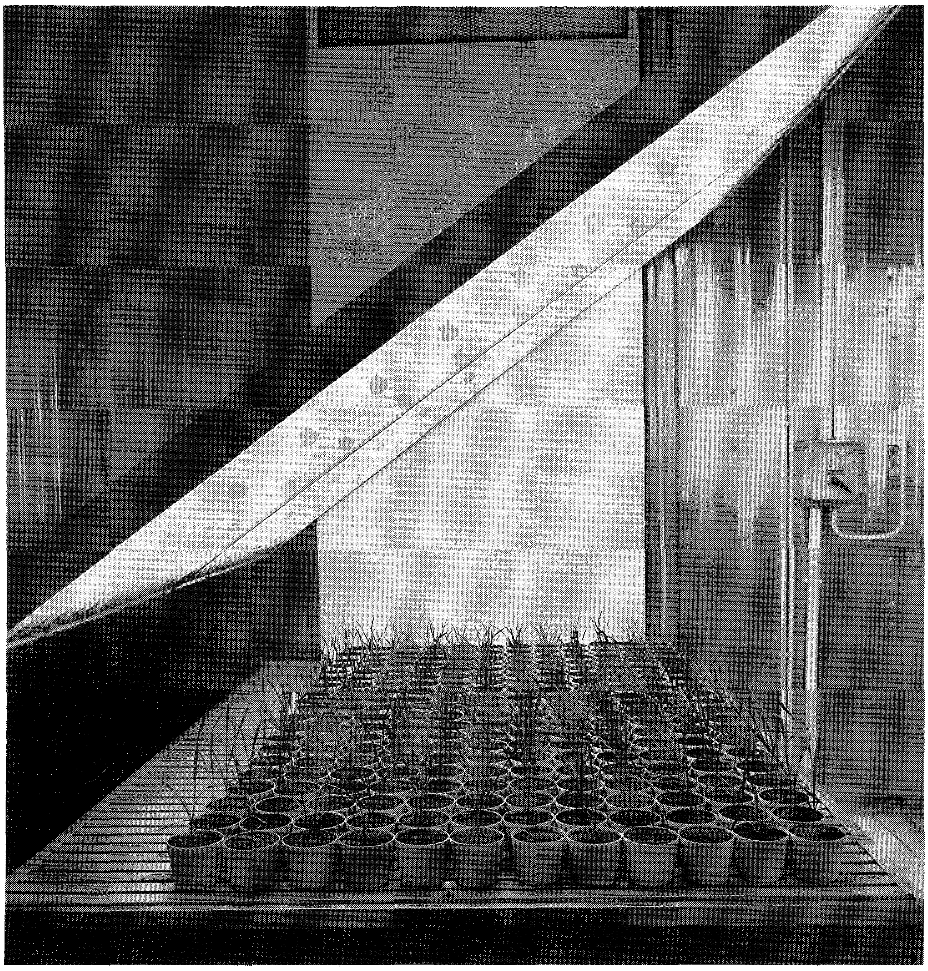

Fig. 1. Creation of cross-gradients for illumination intensity and spectral distribution (increasing red colour range) by means of tilting the light canopy and using fluorescent lamps with different spectra (colours).

satisfactory temperature gradient in this manner, so further solutions were sought.

Construction

In 1979, after a number of attempts the best solution was found to be the use of a mixing bench consisting of 12 separate air ducts, above which plants can be placed in 12 rows (Fig. 3). In each row places for 12 plant pots have been made, so that a total of 12 times 12, i.e. 144 plant pots can be accommodated. Two separate air tanks, of the same size and pressure and insulated from each other, are sited under the 12 air ducts. Two separate acclimatising units supply the two air tanks continuously with air, that from one acclimatising unit being adjusted to the minimum value of the temperature gradient (T_1) and that from the other being adjusted to the maximum value (T_{10}). Each of the 12 air ducts is connected by a damper to both the air tanks. The manually adjustable

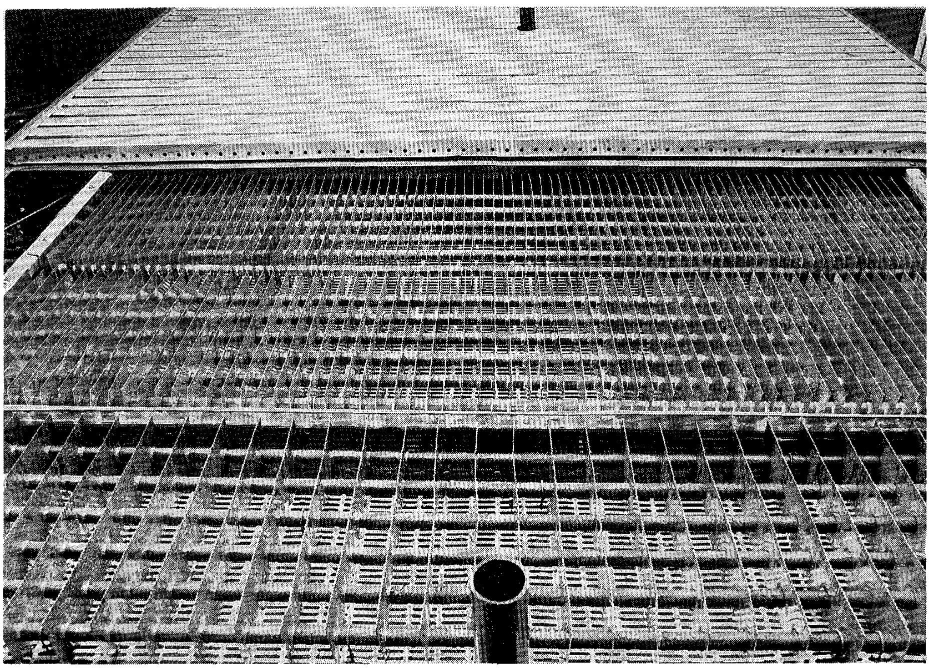

Fig. 2. Supplementary evaporator placed under the plant growth surface, with fins placed at various distances from each other to create a temperature gradient.

Fig. 3. The mixing bench designed to create a temperature gradient in the cross-gradient phytotron unit, with maize plants all sown at the same time.

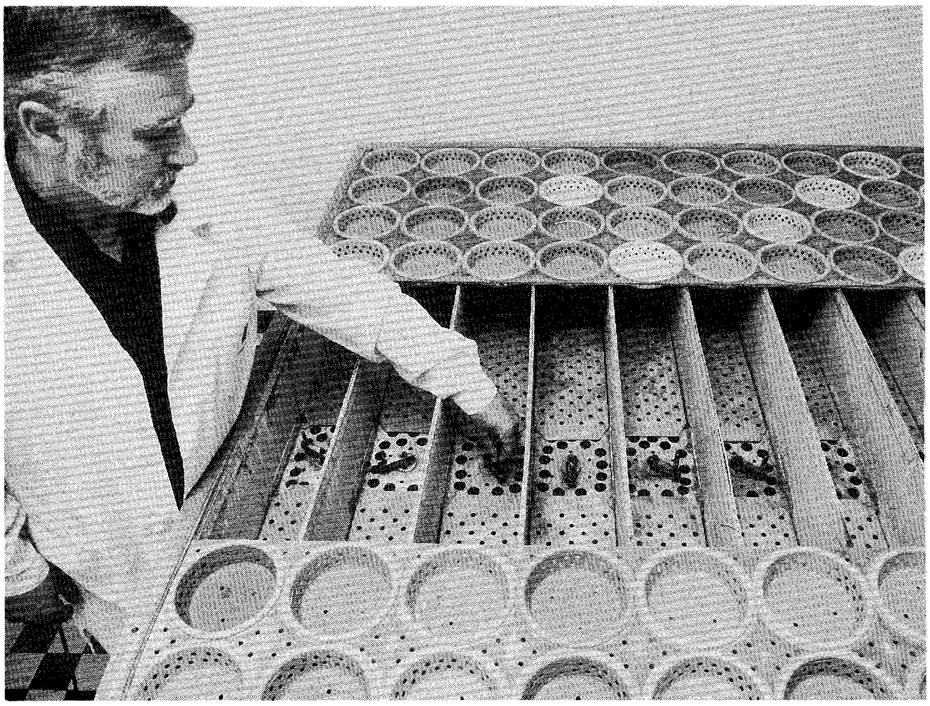

Fig. 4. The dampers belonging to each separate air duct in the mixing bench can be manually adjusted to create a regular gradient.

dampers (Fig. 4) have been constructed so that as they open towards one tank, they close towards the other. This means that all 12 air ducts are supplied with the same quantity of air. The air temperature in each duct can be controlled by adjusting the positions of the dampers. Obviously, air duct 1 is supplied only with air from the T_1 tank and air duct 12 only with air from the T_{10} tank. However, since the two outer air ducts are not considered when evaluating the results due to the so-called edge effect, air ducts 1 and 2 are both adjusted to the minimum temperature and air ducts 11 and 12 to the maximum temperature. The required gradient is set up between air ducts 2 and 11 by supplying them with different mixtures of T_1 and T_{10}. In theory this means that air duct 2 will receive 100% T_1 (cold air) and 0% T_{10} (warm air), duct 3: 90% cold and 10% warm air, duct 4: 80% cold and 20% warm air, duct 5: 70% cold and 30% warm air, and so on, until we reach duct 11, which will be supplied with 0% cold and 100% warm air. In practice the extent to which the dampers are opened is adjusted by measuring the air temperature in the given duct.

Naturally, within each air duct there are differences of a few tenths of a degree centigrade depending on the position in the duct. However, the efficiency of the mixing table means that the temperature difference within the air ducts is always less than the difference between neighbouring ducts due to the gradient. In other words, all the plants above a given air duct are guaranteed to be at a lower temperature than any of the plants above the next air duct. The maximum gradient which can be produced is 10℃, which means that air ducts 2 to 11 differ from each other at 1℃ intervals. In this case the differences within any given air duct are less than +/−0.5℃. If in the following experiment the gradient is reduced to half, i.e. to 5℃, the difference between one air duct and its neighbour will be 0.5℃ and the differences within each air duct will be less than +/−0.25℃. In other words, any point in air duct 2 will be colder than any points in air duct 3, and the same will be true of points in air ducts 3 and 4, 4 and 5, and so on up to air duct 11. Thus, the air ducts become gradually warmer from duct 2 up to duct 11.

Technical parameters

The gradient bench has a growing area of 3.3 m^2 and will take 144 pots (100, excluding the edge pots). The largest pots which can be accommodated have a base diameter of 10 cm. The height of the growing area is 1.5 m. The temperature can be adjusted between +5℃ and +35℃, with a gradient of 0–10℃ intervals. The maximum photosynthetic photon flux density (PPFD) is 400 $\mu molm^{-2}s^{-1}$, which can be reduced by altering the position of the light canopy. The illumination can be switched on and off in 6 steps. The maximum PPFD gradient is 100 $\mu molm^{-2}s^{-1}$. The air flows upwards vertically between the plants. The rate of flow on the floor of the growing area is 0.6 ms^{-1}.

Naturally, if air at the same temperature but with different gas concentrations (e.g. CO_2) is fed into the two air tanks, the mixing bench will create a gradient for the given gas.

EXPERIMENTS

Perpendicular to the temperature gradient a cross gradient can be formed by slanting the light canopy as mentioned above to give a light gradient or by applying increasing rates of a given chemical (e.g. herbicide, fertiliser, etc.) to give a "treatment" gradient. But this cross "gradient" could also consist of different plant varieties, or of some disease or environmental pollutant.

Temperature and light gradients

The first experiment carried out using the mixing bench to create a cross gradient was a paprika experiment set up by Kristóf (*4*) in order to study the interaction of heat and light and to determine the lowest temperature at which the growth and yield potential of paprika plants is still acceptable. Using a single experiment (with a cross gradient of 15–25℃ temperature and 10–20 klx illumination) it was demonstrated that in the case of the paprika variety *Soroksári hajtató* a temperature of 15–18℃ was unfavourable, between 19 and 22℃ growth and development were satisfactory, but the stand was heterogeneous, while the 23–25℃ range was favourable in all respects. A higher level of illumination accelerated bud and flower formation and increased the earliness of the yield (*4*).

Temperature and chemical gradients

Experiments carried out by Nagy and Berzsenyi (*5*) are a good example of experiments involving a temperature gradient perpendicular to a chemical gradient. The cross gradient was formed by temperatures of 16–26℃ and 1–2–4–8–16 l/ha rates of the herbicides EPTC and ethiolate. In a single experiment an analysis of the 50 different temperature and herbicide rate values for each herbicide indicated that in the case of EPTC maize was damaged by rates of 4–8–16 l/ha, but only at temperatures above 21℃, while for ethiolate real deformities were only observed at 16 l/ha and 21℃, though at any temperature the 8–16 l/ha rates led to a reduction in shoot length and green mass.

A similar experiment was carried out by Berzsenyi and Győrffy (*6*), who programmed a temperature gradient of 13–22℃ with a cross gradient consisting of various rates of the herbicide acetochlor (0–1–2–4 l/ha), the herbicide rates plus antidote AD-67 (10%) and the herbicide rates plus antidote DKA-24 (10%). Each pot, sown with 12 maize seeds, represented a different combination, 100 in all, of temperature and herbicide, or temperature and herbicide+antidote values. Naturally the other environmental factors, such as light, atmospheric carbon dioxide concentration, etc. were the same for all the plants in the experiment.

It is also worth mentioning experiments carried out by Hamar (*7, 8*), who investigated the effect of seed treatment with polyethylene-glycol or osmotic agents, and of preliminary germination on the germination of paprika at various temperatures. As the result of an experiment carried out on the gradient bench it proved possible to demonstrate that the treatments caused an average reduction of 0.8℃ in the minimum temperature required for 50% emergence, leading to an acceleration in emergence of 1.8–7.0 days depending on the temperature.

Soil temperature and soil moisture gradients

Anda and Pintér (*9*) examined the effect exerted on the germination and development of sorghum by the gradient developing in the soil as the result of the temperature gradient created by the air flowing upwards around the pots. In this experiment the cross gradient was formed by high and low values of soil moisture content.

Temperature gradient

As a special case, Marton (*10, 11*) used various inbred maize lines to create a "cross gradient" perpendicular to a temperature gradient in order to examine their emergence and initial growth. In another experiment by Marton *et al.* (*12*) involving inbred maize lines the "cross gradient" to the temperature gradient was represented by four different Fusarium species. Prior to sowing into sterile soil, the seeds were soaked for 24 hours in suspensions of the four Fusarium species or in distilled water (control).

CONCLUSIONS

These examples of experiments carried out using the cross-gradient growth bench will serve as an illustration of the possibilities latent in this equipment, which differs fundamentally from traditional plant growth units. If the gradient values are well chosen a single experiment may suffice to determine the optimum values of the two environmental factors, leading to a substantial saving in energy, time and experimental material. It should also be noted that the gradient treatment can also be programmed in time, in which case time represents a third variable parameter in addition to the two factors programmed in the cross gradients. This means that the cross gradient can be created during a given period of the growth cycle, during repeated periods, or throughout the whole growth cycle.

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