TRANSFERABILITY OF PLANT-CLIMATE-REACTION PARAMETERS (GROWTH CHAMBERS, GREENHOUSES AND FIELDS)

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出版情報：BIOTRONICS. 20, pp.31-42, 1991-12. Biotron Institute, Kyushu University
バージョン：
権利関係：

BIOTRONICS **20**, 31–42, 1991

TRANSFERABILITY OF PLANT-CLIMATE-REACTION PARAMETERS (GROWTH CHAMBERS, GREENHOUSES AND FIELDS)

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(Received November 20, 1990; accepted May 3, 1991)

KRUG H. and FINK M. *Transferability of plant-climate-reaction parameters (growth chambers, greenhouses and fields)*. BIOTRONICS **20**, 31–42, 1991. Using growth models at high abstraction level the reactions of radish (*Raphanus sativus* var. *sativus)* growth components (leaf weight ratio, specific leaf area, leaf area ratio, net assimilation rate) to photosynthetic photon flux density and air temperature were tested in growth chambers, greenhouses and in the field. The levels of the morphological components are about identical. Net assimilation rate was somewhat lower in the greenhouses and distinctly lower in the field, compared to the values in the growth chambers. The qualitative reaction pattern of growth components to temperature and radiation was about equal and is described in detail. The causes for differences in quantitative growth performance are discussed.

Key words : *Raphanus sativus* ; leaf weight ratio ; specific leaf area ; net assimilation rate ; *PPFD* ; air temperature.

INTRODUCTION

For operational planning and the control of plant production the relationship between plant growth/development and climate has to be parameterized. Parameterization can be based on experiments in various technical installations or in the field and different models can be used. Each of these tools has its specific benefits and limitations.

In the *open field* the conditions of plant growth are close to practice and the effects of growth factors can be analysed by statistical approaches (e.g. regression analysis). The efficiency, however, is limited due to natural rhythms and variability of the climatic factors, the correlations and interactions between them, the rare occurence of extreme conditions and the influence of uncontrolled factors which complicate the transferability to other years or sites. The efficiency can be improved by varying input intensities artificially (e.g. irradiance and day length by successive plantings, day length by artificial photoperiodic effective light, watering a.o.).

Growth chambers in comparison to field conditions have many advantages. They enable the control of nearly all essential growth factors in a wide range of combinations. Thus they allow to test specific constellations, as e.g. stress conditions and particularly, to disentangle complex interactions. Furthermore they permit to control a wide range of climate programs, from extreme or natural oscillations and fluctuations to extreme simplifications, as e.g. constant set points. These abilities facilitate or enable the evaluation, but with increasing differences to the performance of the natural growth factors (e.g. light quality, light- or temperature gradients and their dynamics) or in the "environmental rest complex" (e.g. air velocity, CO_2-concentrations), problems in transferability may arise.

From a methodological point of view, experiments to disentangle plant-climate relationships in *greenhouses* can be classified between those mentioned above. Regarding protected cultivation they are close to the natural sites. When analysing field relationships, the enviromental conditions in greenhouses correspond more to natural conditions than in growth chambers, but correlations between the input factors can be more effectively broken than in the field. Furthermore, oscillations and fluctuations can be diminished or increased by heating, watering, CO_2-enrichment and other means. Finally, greenhouse experiments are cheaper than growth chamber experiments with regard to investment and running cost.

Other problems may arise by cultivating the plants in trays or pots concerning root expansion, root environment, crop architecture and therewith crop canopy surface and microclimate.

As for the comparability of plants grown in growth chambers, greenhouses or fields some statements have been published:

Went (*16*) concludes in his fundamental book "The experimental control of plant growth: "... When the conditions in the greenhouses reflect those in the field the plant responses are also similar. By using air conditioned greenhouses the field conditions can be maintained for any length of time which make them so much superior to field testing".

Evans (*4*) reviews the consequences of oscillations and fluctuations of climatic factors concerning short term and long term plant growth and development in natural and artificcial climates.

Raper and Downs (*14*) state "... that a characteristic field phenotype for tobacco can be approached, if not duplicated, in CERs (growth rooms) by rather simplistic and brosd simulations of a field environment" and "... direct observations of growth responses to environmental influences can be extrapolated from controlled environments to field culture provided that the environmental variables were applied within the context of a "normal" field progression" or "... data gained from phytotron experiments can be incorporated into dynamic models of plant growth, if environmental parameters and physiological state of the plant are adequately noted". In this paper, however, no direct comparison of the intensities of the climatic factors is presented.

Krug (*5, 6*) reports on physical and physiological problems of plant growth in

controlled and uncontrolled environments and of the efficient use of growth chambers. Begg and Box (*2*) discuss the importance of different root environments. Aust and Bretschneider-Herrmann (*1*) state that plant culture in growth chambers due to different environmental conditions causes different growth patterns compared to field growth and concerning the pathosystem "... in general the results obtained in a controlled environment were found useful for explaining the causal relations in pathosystems. However, it is not possoble to replace field trials by growth chamber experiments, if results are wanted which concern quantitative relations within a pathosystem".

In *summary* it can be concluded, that some approaches are published to compare growth chamber, greenhouse and field growth, but quantitative comparisons are lacking. Therefore, experiments performed in different installations to elaborate parameters for modelling radish growth for production planning and production control are used to check the transferability of growth parameters to radiation and temperature. Transferability would allow to generalize experiments performed in different installations, to integrate parameters evaluated in different installations and to combine the benefits of the installation for parameterizing plant growth.

MATERIALS AND METHODS

To model plant growth as a function of irradiance and temperature, radish plants (*Raphanus sativus* var. *sativus*, cv. Kutara and Hilmar) were grown in growth chambers under a wide range of environmental conditions. To ensure transferability in horticultural practice, experiments were carried out later on in greenhouses and in the open field.

In the *growth chambers* (more details see *10*) plants were grown under controlled light, temperature, air humidity, CO_2-concentration and water supply. Light was supplied by VHO-Sylvania Cool White Fluorescent Lamps, day length was controlled to 16 hours per day, CO_2-concentration to 350 $\mu l\ l^{-1}$.

Seeds were sown 6×6 cm into 6 litre pots filled with soil mixed with peat (sand 20%, silt 70%, clay 10%, C=1%). Water was supplied daily according to weight to 45 and 85%, respectively, of maximal water capacity of the pots (about 300 and 30 hPa resp.). This difference did not affect the characters measured. Every pot was supplied with 5 g fertilizer ($N:P_2O_5:K_2O=12:12:20$) and sodiummolybdate.

To simulate leaf expansion and light interception in canopies, the plants in each pot were surrounded by a green plastic cuff with 65% holes (Fig. 1), which was gradually adjusted to the surface of the canopy. Until an emergence rate of 50% was achieved, the pots were kept at 15°C, thereafter subjected to the different environments.

In the *greenhouses* (details see *7, 8*) seeds were planted 6×6 cm into trays (60 ×40 cm, 15 cm layer of natural soil), surrounded by cuffs of the same material as used for the pots. Water was applied subjectively striving for optimal soil humidity. CO_2-concentration varied between 300 and 500 $\mu l\ l^{-1}$ with a mean

Fig. 1. Radish plants in a pot with a green, holed cuff, adjusted to the canopy surface.

concentration of about 380 μl l^{-1}. Until a 50% emergence rate was achieved the plants were kept in greenhouses at a temperature of about 14℃ and then transferred to the climate treatments, where the trays were dug to soil level to ensure natural soil temperature.

In the *open field* seeds were planted 6×6 cm into the natural soil (sand 75%, silt 14%, clay 6%, C=1.5%) in successive sets from March to September. Water was supplied subjectively, but optimal soil humidity was more difficult to achieve than in the greenhouses. To vary the irradiance some plots were covered with shading clothes at 1 m height to diminish diverging microclimatic conditions. Fertilization was kept as close to the optimum as possible (about 10 g N m^{-2}) at all sites. Monthly means of CO_2-concentration varied between 310 μl l^{-1} (July, August) and 340 μl l^{-1} (April, October) with a mean concentration of 320 μl l^{-1}.

In the growth chambers photosynthetic photon flux density (*PPFD*) was measured with LiCOR Quantum Sensor (400–700 nm). In the greenhouses and in the field radiant flux density was measured with Kipp and Zonen solarimeters (300–3800 nm) and converted to *PPFD* according to McCree (*13*): 1 W m^{-2} global radiation=2.3 μmol m^{-2} s^{-1} photo-synthetically active radiation.

To calculate the mean growth rates, an emergence rate of 50% was dated and growth parameters were measured by successive harvestings of each set. This allowed to compute the parameters of the logistic growth function of Feldmann (*7*), which was used to calculate the mean growth rates of the tubers from emergence to harvest weight (4 g fresh or 200 mg dry weight).

The response to radiation and temperature was parameterized by calculating the response surfaces using a multiplicative regression function (*9*). The calculations were made for all data collected (temperature 9-22℃, *PPFD* up to 20 mol m^{-2} d^{-1}). The regression lines are presented for a temperature of 15℃ with

symbols in the range of 13–17°C (Figs. 4, 6 and 8) and for a *PPFD* of 4. 8 mol m^{-2} d^{-1} with symbols in the range of 3.6–6.1 mol m^{-2} d^{-1} (Figs. 2, 3, 5, 7 and 9).

The parameters calculated were used for the growth analysis:

$$RGR \text{ (Relative Growth Rate)} = LAR \cdot NAR \cdot \quad LAR = LWR \cdot SLA$$

$$RGR = \left(\frac{1}{W} \cdot \frac{dW}{dt}\right)$$

$$LWR \text{ (Leaf Weight Ratio)} = \left(\frac{LW}{W}\right)$$

$$SLA \text{ (Specific Leaf Area)} = \left(\frac{LA}{LW}\right)$$

$$NAR \text{ (Net Assimilation Rate)} = \left(\frac{1}{LA} \cdot \frac{dW}{dt}\right)$$

W=weight; LW=leaf weight; LA=leaf area; t=time

RESULTS

As shown in Table 1 the r^2-values of the response surfaces are rather hig... In comparing the different sites, they are highest in the growth chamber experiments and lowest in the field (except for *LAR*).

Table 1. Variability (r^2 of the response surfaces) of growth parameters in different sites

	n	*RGR*	*NAR*	*LAR*
Growth chambers	38	0.94	0.92	0.58
Greenhouses	61	0.94	0.90	0.28
Open field	69	0.60	0.81	0.44

Concerning the level of the growth parameters, there were no evident differences in the morphological reactions determined as *LWR* (Fig. 2), *SLA* (Fig. 3) and the product of these factors, the *LAR* (Figs. 4 and 5). There was only a tendency for a lower *LWR* and consequently a lower *LAR* in the growth chambers compared to field and greenhouse conditions. *NAR*, however, showed a clear range with decreasing values from growth chamber to greenhouse and to field data (Figs. 6 and 7). In a regression plot the *NAR*-values of the greenhouses and field were parallel to those of the growth chambers, with a constant distance. *RGR*, being the product of *LAR* and *NAR*, showed a corresponding response surface (Figs. 8 and 9).

The responses to temperature and photon flux density in the range of 9–22°C were:

- *LWR* increased linearly with temperature and decreased slightly with increasing *PPFD* (Fig. 2). In the greenhouses a more pronounced decrease is indicated.
- *SLA* increased with temperature in the growth chambers and in the field. In the greenhouses no temperature reaction was evident. *SLR* decreased with

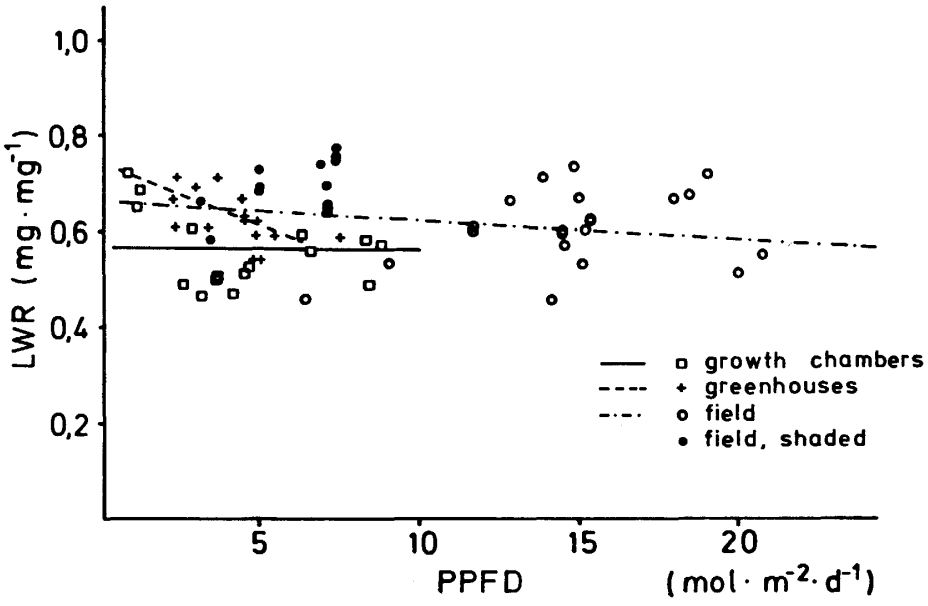

Fig. 2. Leaf weight ratio (*LWR*) of radish plants in growth chambers, greenhouses and fields (unshaded and shaded) as a function of *PPFD* (temperature range 9–22℃, symbols for 13–17℃, regression line for 15℃).

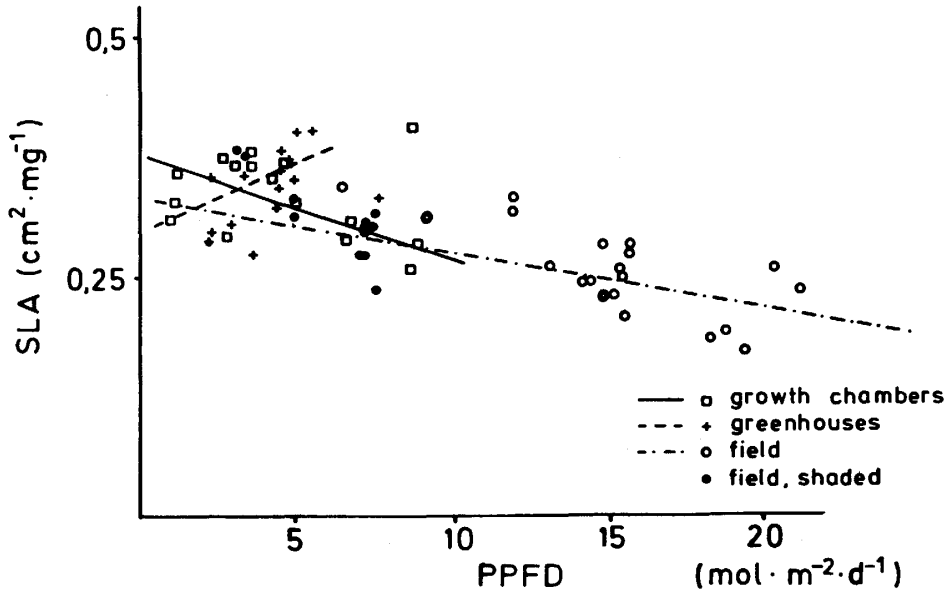

Fig. 3. Specific leaf area (*SLA*) of radish plants (see Fig. 2).

increasing radiant exposure in the growth chambers and in the field, but not in the greenhouses (Fig. 3).

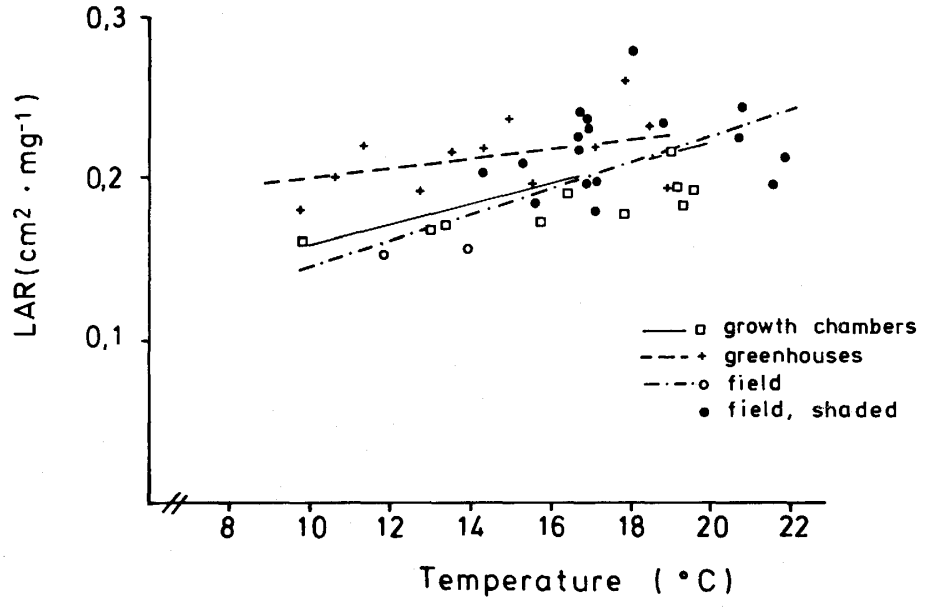

Fig. 4. Leaf area ratio (*LAR*) as a function of temperature (PPFD up to 20 mol m^{-2} d^{-1}, symbols for 3.6–6.1 mol m^{-2} d^{-1}, regression line for 4.8 mol m^{-2} d^{-1}).

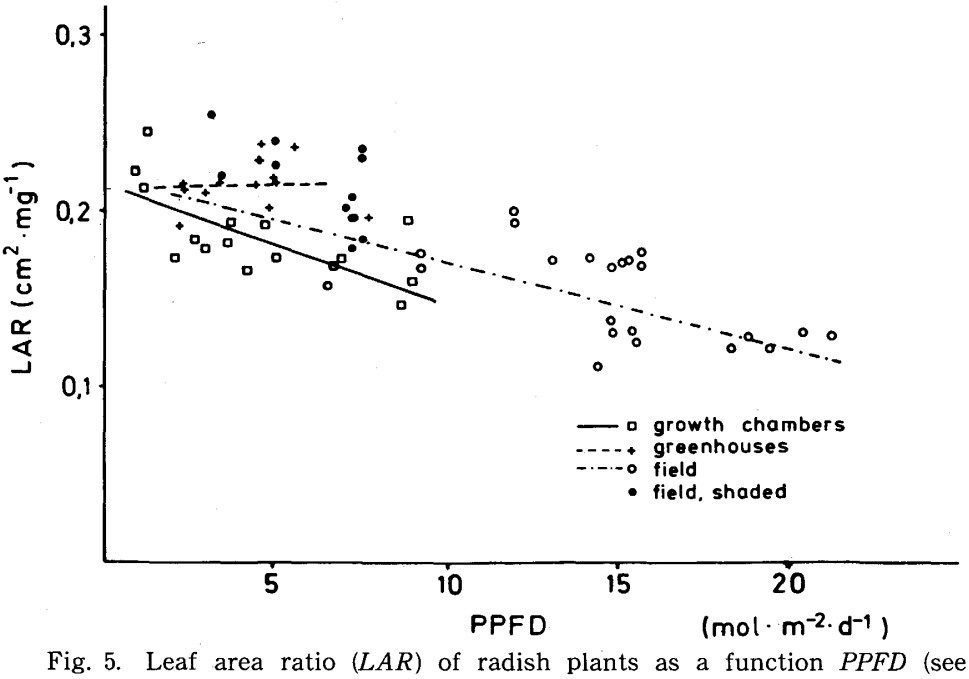

Fig. 5. Leaf area ratio (*LAR*) of radish plants as a function *PPFD* (see Fig. 2).

– The reaction in *LAR* was even more distinct than that of its factors, increasing linearly with temperature at all 3 sites (Fig. 4) and decreasing with radiant exposure except in the greenhouses (Fig. 5).

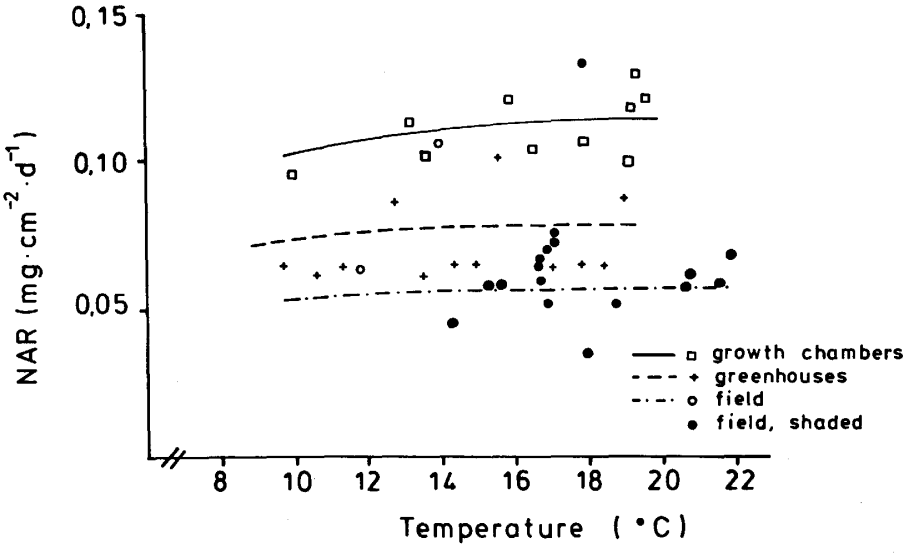

Fig. 6. Net assimilation rate (*NAR*) of radish plants as a function of temperature (see Fig. 4).

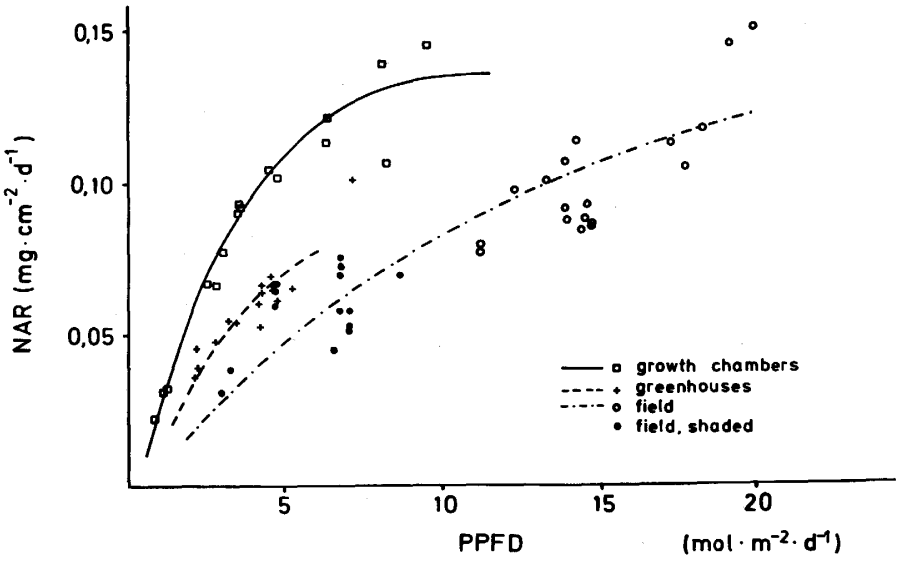

Fig. 7. Net assimilation rate (*NAR*) of radish plants as a function of *PPFD* (see Fig. 2).

– *NAR* showed no reaction to temperature in the range tested (Fig. 6) but increased logarithmically with radiant exposure (Fig. 7).

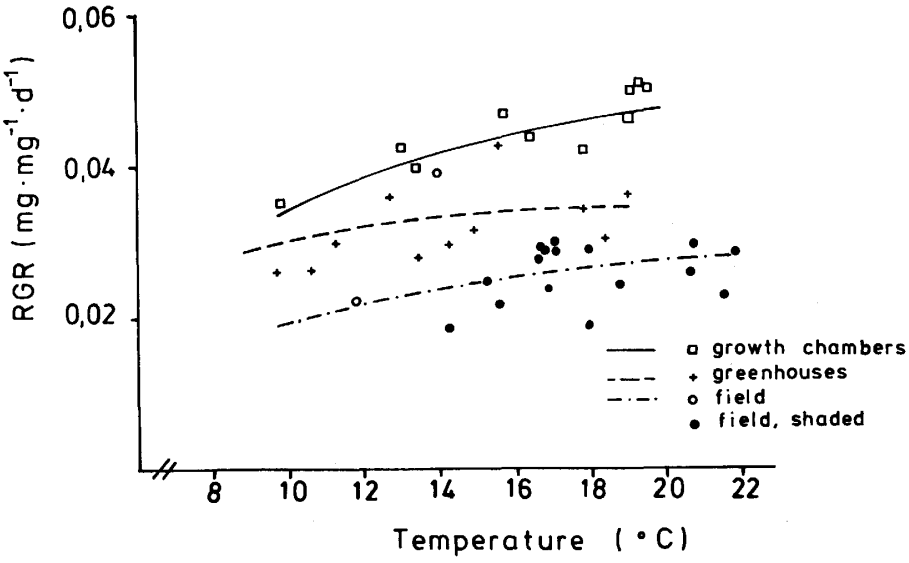

Fig. 8. Relative growth rate (*RGR*) of radish plants as a function of temperature (see Fig. 4).

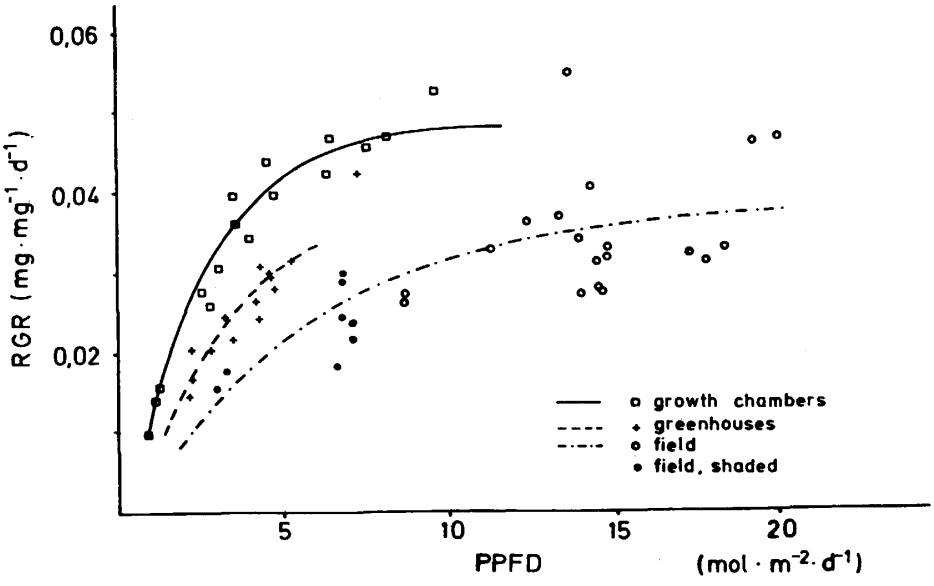

Fig. 9. Relative growth rate (*RGR*) of radish as a function of *PPFD* (see Fig. 2).

– *RGR*, the product of these factors, showed a small increase with temperature in the range tested (Fig. 8) and a distinct logarithmic increase with *PPFD* (Fig. 9).

In general the reaction to temperature was small, if *LAR* was excepted.

DISCUSSION

With the species and cultivars tested the morphological characteristics (*LWR, SLA, LAR*) in the growth chambers, in the greenhouses and in the open field were nearly identical. Small differences can be referred to different ranges of the respective climatic conditions, to not controlled environmental factors and to random variation. With *NAR*, however, there were distinct differences. The highest values were obtained in the growth chambers, closely followed by *NAR* in the greenhouses. The lowest values were observed in the field. These reactions may be caused by

- Light valuation: The portion of *PAR* in natural global radiation was defined to 50%. According to Szeicz (*15*) this value changes according to the season. In summer it is about 45%, in winter 50%, which means that the conversion factor changes. A lower *PAR* portion in summer will result in lower *NAR* values, but is not responsible for the total differences between growth chambers and field values.
- Light quality: As shown by Brückner (*3*) for high-pressure-sodium-lamps, constant additional artificial light in winter results in higher growth rates (factor 1.4) than corresponding fluctuating natural photon flux density. This factor can not be transferred to the light used in the growth chambers but a similar effect may contribute to the deviating reaction.
- Differences in CO_2-concentration, which were comparable in the growth chambers (350 $\mu l\ l^{-1}$) and in the greenhouses (mean about 380 $\mu l\ l^{-1}$, with lower values at noon at the highest irradiances), but CO_2-concentration was lower in the field (about 320 $\mu l\ l^{-1}$).
- Differences in the water status of the plants due to insufficient water supply and lower air humidities in the greenhouses and particularly in the field. The water status may have effected stomatal resistance and thus *NAR*.

The first two factors can be corrected with more detailed experiments: The CO_2-factor could be considered by more detailed measurements and model calculations. A correction would increase *NAR* of the field crops and diminish the difference to the others. The water status could be improved by more exact watering, but the effect of air humidity and wind are difficult to evaluate.

Despite the differences in *NAR*, the experiments show, that, as far as radish is concerned,

- Cultivation in pots is comparable to that in natural soil, if leaf area is restricted by suitable cuffs.
- Diurnal oscillations, fluctuations and seasonal trends in the field (April to October) are integrated by the plant as far as morphological characters are concerned. Furthermore the mean responses are comparable to corresponding means in growth chambers.

This result, however, cannot be generalized. Radish (var. *sativus*) is a relatively insensitive species: Short growth period; small response to diurnal temperature amplitudes (Krug, unpublished data); to elevated CO_2-concentration at low irradiances (*12*) and to photoperiod; no generative development until harvest and no phases of high sensitivity to environmental factors. For kohlrabi (*Brassica oleracea* var. *gongylodes*), too, a high ability to buffer fluctuating weather conditions is demonstrated (Fink unpublished data). With species with a higher canopy (light gradiant), more difficulties in transferability are to be expected. A rather good transferability, however, has been proved with respect to predominant factors as vernalization of cauliflower (*17*). That means, that transferability has to be tested for every type of reaction and the objective has to be considered.

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