Combined Effects of Root and Night Air Temperatures on the Growth and Mineral Nutrition of Cucumber

I. The Effect on Growth

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(Received February 17, 1988)

Growth responses of young cucumber plants (*Cucumis sativus* L.) to various root and night air temperature combinations were determined. Seedlings were grown hydroponically in a growth chamber at different root temperatures (13°, 18°, 23° and 28°C) and air temperatures in the night (12°, 17° and 22°C). Daytime air temperature was maintained at 27°C. A combination of 28°C root temperature and 22°C night air temperature gave the maximum growth rate. Irrespective of night air temperature, a higher root temperature resulted in a higher growth rate. However, the root zone warming was less effective in growth promotion when combined with lower night air temperatures, mainly due to a decrease in its efficiency of increasing leaf area. These results suggest that in cucumber, in the early vegetative growth stage, an increase in root temperature does not increase growth rate to an extent that can compensate the growth reduction caused by low air temperature in the night.

INTRODUCTION

Plant growth is under the control of temperature not only of the air but also in the root zone. Much research effort has been focused on the possibility of lowering the air temperature at night with minimum reduction of crop productivity, in view of saving the heating costs in greenhouse crops.^{1,14-16)} Tomatoes grown at reduced night air temperature can produce equivalent yields to those grown at higher temperature, provided that the root temperature is concurrently maintained at an optimum level.^{10,14)}

Cucumber is more thermophilic than tomato.⁷⁾ In greenhouse cucumber, therefore, saving the heating costs is a matter of great significance for cutting down the cost of production. However, there are little evidence so far that the root zone warming secures a reduction in night air temperature in greenhouse cucumber. Growth and crop productivity of cucumber grown at reduced night air temperature is improved by raising the root temperature.^{4,9)} But the effect is usually small. Furthermore, according to Hori et al.,⁶⁾ root zone warming was more effective at higher than at lower day/night air temperature. Detailed inquiry into growth responses of cucumber to various root and night air temperature combinations seems important. The present investigation was therefore carried out to determine the combined effects of root and night air temperature on the growth and various growth parameters, using young cucumber plants in the first place.

MATERIALS AND METHODS

Five seedlings of cucumber (cv. Kurume-ochiai H), raised hydroponically in a glasshouse, were planted at the first leaf stage to each of 4 reservoirs in a growth chamber. Each reservoir contained 30 l of one half strength Hoagland No. 2 solution. Solutions were vigorously aerated and continuously circulated with a water pump. The reservoirs were immersed in a large water bath. Temperature of the bath water was maintained at 20°C by means of continuous circulation of the water through a temperature control unit. Light was provided by Toshiba metal halide lamps for 12 h per day, with an irradiance at $210 \mu\text{mol}\cdot\text{m}^{-2}\text{ s}^{-1}$ (400–700 nm) at plant level. Air temperatures during the day and night were 27° and 20°C, respectively.

One day after planting temperature of the bath water was lowered to 11°C and the solution temperatures (=root temperatures) in the 4 reservoirs were established at 13°, 18°, 23° and 28°C, respectively. Night air temperature was controlled at 12°, 17° or 22°C, with daytime air temperature at 27°C throughout. Since only one growth chamber was available, the different night temperatures were run consecutively. Therefore, each of three separate experiments consisted of one night air temperature and four root temperatures.

After 7 days growth under these different temperature conditions, plants were harvested and determined for fresh weights of leaf blades, stem plus petioles and roots, leaf areas and total root length. Tissues were oven-dried at 60°C for 2 days and determined for dry weights. To calculate a relative growth rate (RGR), dry weights of test plants at the onset of temperature treatments were estimated by their fresh weights and the mean dry matter percentages of remnant plants of similar size with the test plants.

RESULTS AND DISCUSSION

Both root and night air temperatures exerted a significant influence on the growth of cucumber plants (Figs. 1, 2). Maximum RGR was obtained at a combination of 28°C root temperature and 22°C night air temperature (Fig. 2). On the other hand, the effect of night air temperature on the growth disappeared at a root temperature of 13°C, and the growth was determined exclusively by the root temperature. Hori et al.⁶⁾ observed a similar trait with cucumber and concluded that 13°C was a lower limit for the growth of cucumber.

Although the rise in root temperature significantly increased RGR in all night air temperature regimes, the increase was more marked when the night air temperature was higher. This observation, consistent with that by Hori et al.,⁶⁾ suggests that root zone warming brings about a greater growth promotion when associated with higher night air temperatures.

Several workers demonstrated that the optimum root temperature for growth shifted up to a higher temperature when the air temperature was lower.^{5,9,13)} In the current study, however, no such trend was observed. In another experiment, in which 30° and 35°C root temperatures were included, maximum growth was obtained at 30°C, regardless of night air temperature. Kleinendorst and Brouwer¹¹⁾ also found no difference in the optimum root temperature with changes in a daily air temperature in perennial ryegrass.

Fig. 1 Effects of root temperature on the growth of cucumber at different air temperatures in the night. Standard errors are smaller than the symbols, unless otherwise indicated.

Fig. 2 Effects of root temperature on the relative growth rate of cucumber at different air temperatures in the night. Standard errors are smaller than the symbols, unless otherwise indicated.

It is of interest to note that root growth at a root temperature of 13°C was greater as the night air temperature was lower (Fig. 1). Similar observations were reported by Hori et al.⁹⁾ with cucumber and Gosselin and Trudel⁹⁾ with tomato. It is known that the percent distribution of photosynthates to roots increases with lowering in night air temperature.^{8,17)} This effect of low night air temperature may become more evident at low than at high root temperature, presumably because of reduced photosynthate expenditure by respiration in the roots.

Top-root dry weight ratios (T/R) showed a trend to decrease as root temperature was reduced from 28~23°C to 18°C. But they turned to rise when the root temperature was further reduced to 13°C (Fig. 3). This rise was very marked in the 22° and 17°C night air temperature regimes, but was only slight in the 12°C regime. The decrease in T/R with lowering in root temperature is considered an adaptation reaction of plants to low root temperature.^{11,18)} Therefore, the sharp rise of T/R at 13°C is indicative of a failure in the adaptation. Higher T/R values at 13°C with higher night air temperatures were clearly caused by a greater reduction of root growth.

Total leaf area of a plant was linearly related with root temperature in all three night air temperature regimes (Fig. 4). Here also, root temperature exerted a much greater influence when the night air temperature was higher. It is well known that a leaf area increase is generally one of the most distinct effects of raising root temperatures.³⁾ Perhaps, the effect of high root temperature in stimulating leaf extension growth was largely offsetted by low night air temperature. Presumably, inhibition of leaf area increase was a major cause of limited efficiency of root zone warming at low

Fig. 3 Effects of root temperature on the top-root ratios of cucumber at different air temperatures in the night. Standard errors are smaller than the symbols, unless otherwise indicated.

Fig. 4 Effects of root temperature on the total leaf area of a cucumber plant at different air temperatures in the night. Standard errors are smaller than the symbols, unless otherwise indicated.

Fig. 5 Effects of root temperature on the water content of cucumber leaves at different air temperatures in the night. Standard errors are all smaller than the symbols.

Fig. 6 Effects of root temperature on the mean thickness of cucumber leaves at different air temperatures in the night. Standard errors are smaller than the symbols, unless otherwise indicated.

night air temperatures. Also, inhibition of photosynthesis was probably involved in the causes, since prolonged preincubation of cucumber plants at 10–12°C aerial temperature is known to cause irreversible suppression of photosynthesis.¹²⁾

Gosselin and Trudel³⁾ ascribed the increase in shoot growth with root temperature to greater leaf area rather than to more efficient photosynthesis in tomato. Cooper³⁾ reported that photosynthetic rate is generally independent of root temperature except at extremes of root temperature. In the present investigation water content of leaves, determined in the day, decreased with lowering in root temperature (Fig. 5). Furthermore, the leaves became chlorotic at 13°C, regardless of night air temperature. Therefore, photosynthetic rate was possibly low at 13°C compared to that at higher root temperatures.

Mean thickness of leaves, expressed in the dry weight of a unit leaf area, showed a trend to become larger toward the lowest root temperature (Fig. 6). Also, the lowering

Fig. 7 Effects of root temperature on the root length of cucumber at different air temperatures in the night. Standard errors are smaller than the symbols, unless otherwise indicated.

Table 1 Statistical analysis of effect of root and night air temperatures on growth and various growth parameters of young cucumber plants.

Factors	Growth parameters ^z				
	RGR	T/R	LA	LT	RL
Root temp. (A)	**Y	**	**	**	**
Night air temp. (B)	**	**	**	**	**
Interaction (A × B)	**	**	**	*	**

^z RGR, relative growth rate; T/R, top-root dry weight ratio; LA, total leaf area; LT, mean leaf thickness; RL, root length.

^y Statistically significant at $P=0.05$ (*), $P<0.01$ (**), respectively.

in night air temperature increased the thickness. In general, low root temperature results in an increase in leaf thickness.³⁾ Together with this, starch accumulates markedly in leaf spongy cells.²⁾

While the increase of root dry weight with increase in root temperature was curvilinear (Fig. 1), root length increased linearly with root temperature (Fig. 7). This difference was attributable to the differed thickness of roots with root temperature: i.e., the roots became thinner as the root temperature was higher, regardless of air temperature in the night.

Statistical analyses of the data are summarized in Table 1. Effects of root and night air temperatures on growth and various growth parameters were all highly significant. Interactions between root and night air temperatures were also highly significant ($P<0.01$) in all parameters, except for the leaf thickness being significant at $P=0.05$.

The current experiments have shown that growth promoting effect of raising root temperature is substantially offsetted by the detrimental effect of low night air temperature in young cucumber. One of the major causes of reduced efficiency of raising root temperature is assumed to be a decrease in its efficiency of increasing leaf area. Leaf mineral nutritions as affected by root and night air temperature combinations will

be reported elsewhere. Further study is required with plants in a reproductive stage of growth.

The author is grateful to Mr. K. Murai for technical assistance during the course of this investigation.

REFERENCES

- 1) ABDELHAFEEZ, A. T., H. HARSSEMA, G. VERI, and K. VERKERK. 1971. Effects of soil and air temperature on growth, development and water use of tomatoes. *Neth. J. Agric. Sci.* **19**: 67-75.
- 2) CHUGUNOVA, N. G., K. YA. BIL', and L. N. CHERMNYKH. 1975. Structure and photosynthesis of cucumber leaves at different temperatures in the root zone. *Soviet Plant Physiol.* **22**: 584-591.
- 3) COOPER, A. T. 1973. Root temperature and plant growth. 1-73. *Commonw. Agric. Bureaux U. K.*
- 4) FUJII, T., T. ITO, F. SHIINA, and K. MINATO. 1962. Studies on the temperature in fruit vegetable culture (1) Effect of air and soil temperature in raising tomato and cucumber seedlings. *Tech. Bull. Fac. Hort. Chiba Univ.* **10**: 59-70.
- 5) GOSSELIN, A., and M. J. TRUDEL. 1983. Interactions between air and root temperatures on greenhouse tomato I. Growth, development and yield. *J. Am. Soc. Hort. Sci.* **108**: 901-915.
- 6) HORI, Y., K. ARAI, T. HOSOYA, and M. OYAMADA. 1968. Studies on the effects of root temperature and its combination with air temperature on growth and nutrition of vegetable crops I. Cucumber, tomato, turnip and snap bean. *Bull. Hort. Res. Sta. Jpn. Ser. A* **7**: 187-214.
- 7) HORI, Y., and K. ARAI. 1971. Studies on the effects of day and night temperature on the growth of vegetable crops I. Growth of young plants of tomato and cucumber affected by day and night temperature and its relation to yield and growth habit of plants after transplanting. *Bull. Hort. Res. Sta. Jpn. Ser. A* **10**: 205-227.
- 8) HORI, Y., and Y. SHISHIDO. 1977. Studies on translocation and distribution of photosynthetic assimilates in tomato plants I. Effects of feeding time and night temperature on the translocation and distribution of ^{14}C -assimilates. *Tohoku J. Agric. Res.* **28**: 26-40.
- 9) ITAGI, T., and T. KANAME. 1961. Effects of various air and soil temperatures on the growth and yield of cucumber under glass and plastic house culture. *Bull. Kanagawa Hort. Exp. Sta.* **19**: 67-75.
- 10) JONES, D. A. G., I. SANDWELL, and C. J. W. TALENT. 1978. The effect of soil temperature when associated with low air temperature on the cropping of early tomatoes. *Acta Hort.* **76**: 167-171.
- 11) KLEINENDORST, A., and R. BROUWER. 1965. The effect of temperature on two different clones of perennial ryegrass. *Jaarb. I. B. S.* **1965**: 29-38.
- 12) LYUTOVA, M. I., I. F. KARPILOVA, V. E. SHARKOVA, and A. K. ROMANOVA. 1985. Effect of temperature on activity of ribulose diphosphate carboxylase from cucumber and muskmelon leaves. *Soviet Plant Physiol.* **32**: 791-794.
- 13) MALETTA, M., and H. W. JANES. 1987. Interaction of root and shoot temperature on dry matter accumulation and root growth in tomato seedlings. *J. Hort. Sci.* **62**: 49-54.
- 14) MORGAN, J. V., and R. O'HAIRE. 1978. Heated hydroponic solutions as an energy saving technique. *Acta Hort.* **76**: 173-181.
- 15) MOSS, G. I. 1984. The effect of root-zone warming on the yield and quality of roses grown in a hydroponic system. *J. Hort. Sci.* **59**: 549-558.
- 16) ORCHARD, B. 1980. Solute heating for the tomato crop. *Acta Hort.* **98**: 19-28.
- 17) SHISHIDO, Y., H. CHALLA, and J. KRUPA. 1987. Effects of temperature and light on the carbon budget of young cucumber plants studied by steady-state feeding with $^{14}\text{CO}_2$. *J.*

Exp. Bot. **38**: 1044–1054.

- 18) TACHIBANA, S. 1982. Comparison of effects of root temperature on the growth and mineral nutrition of cucumber and figleaf gourd. J. Jpn. Soc. Hort. Sci. **51**: 299–308.

〈和文抄録〉

キュウリの生育および無機栄養に及ぼす根温ならびに夜間気温の影響

I. 生育に及ぼす影響

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冬季の施設栽培における暖房コストを低減する目的で低温栽培の可能性が研究されており、トマトなどでは地温を高く維持することによって夜間の気温を下げる事が可能であることが明らかにされている。本研究では、根温と夜間気温を種々に組合せた条件下でキュウリを栽培し、低夜気温によるキュウリの生長抑制が高根温によって補償されるかどうかを調べた。根温は 13°~28°C の 4 水準、夜間気温は 12°~22°C の 3 水準とし、日中気温はいずれも 27°C とした条件下でキュウリ幼植物（品種、久留米落合H型）を 7 日間栽培した。その結果、キュウリの生長は夜間気温にかかわらず根温が高いほど良好となったが、高根温による生長の促進は夜間気温が高いほど顕著であり、夜間の気温が低いと高根温の葉面積増大効果が著しく制限された。これらのことから、キュウリでは、少なくとも初期生長においては、夜間の低気温による生長の抑制が地温を高めることによって補償される可能性は小さいと考えられる。