ROOT TEMPERATURE EFFECT ON ROOT HYDRAULIC RESISTANCE IN CUCUMBER (CUCUMIS SATIVUS L.) AND FIGLEAF GOURD (CUCURBITA FICIFOLIA B.) PLANTS

Yoshida, Satoshi
Biotron Institute Kyushu University

Eguchi, Hiromi
Biotron Institute Kyushu University

https://hdl.handle.net/2324/8168

出版情報：BIOTRONICS. 19, pp.121-127, 1990-12. Biotron Institute, Kyushu University
バージョン：
権利関係：

BIOTRONICS **19**, 121–127, 1990

ROOT TEMPERATURE EFFECT ON ROOT HYDRAULIC RESISTANCE IN CUCUMBER (*CUCUMIS SATIVUS* L.) AND FIGLEAF GOURD (*CUCURBITA FICIFOLIA* B.) PLANTS

S. YOSHIDA and H. EGUCHI

Biotron Institute, Kyushu University 12, Fukuoka 812, Japan

(Received July 11, 1990; accepted August 9, 1990)

YOSHIDA S. and EGUCHI H. *Root temperature effect on root hydraulic resistance in cucumber* (Cucumis sativus *L.) and figleaf gourd* (Cucurbita ficifolia *B.) plants.* BIOTRONICS **19**, 121–127, 1990. The effect of root temperature on total root resistance (hydraulic resistance in a whole root system) was examined in detached whole root systems of cucumber and figleaf gourd plants by applying the suction of 80 kPa in root temperature region of 8 to 32°C. The total root resistances in both species became higher at lower root temperatures. From the fact that radial root resistance is about 80% of total root resistance, it could be conceivable that the temperature effect on the total root resistance is associated with the permiability in the root cell membrane in response to root temperatures. Furthermore, the species specificity was clearly found in significant difference (5% level) in total root resistance between two species: The total root resistance in the cucumber root system was higher than that in the figleaf gourd root system at 8°C.

Key words: *Cucumis sativus* L.: cucumber plant; *Cucurbita ficifolia* B.; figleaf gourd plant; water uptake rate; hydraulic resistance; total root resistance; osmotic potential of xylem sap; root temperature; low temperature tolerance.

INTRODUCTION

Rhizosphere environment is responsible for plant water relations (*2*, *13*). It is well known that lower soil temperatures reduce water absorption in roots and induce a water deficit in shoots (*11*). Boyer (*1*) has reported that the hydraulic resistance in a root system was larger than 50% of that in a whole plant. Furthermore, Kramer (*12*) has found the species specific differences in the water absorption by intact plants responding to lower soil temperatures among several plant species, and Kaufmann (*9*) has proposed a hypothesis that the effect of root temperature on plant water relations is different between the chilling sensitive plant and the chilling tolerant plant because of different temperature effects on root permeability. Eguchi and Koutaki (*4*) have reported that the transpiration rate in a cucumber plant grafted on a figleaf gourd stock is kept higher even in the case that the transpiration rate in an intact cucumber plant is reduced at low soil temperatures of 10°C. These facts indicate that the soil temperatures affect the water relations in whole plants through hydraulic properties of roots.

The present paper deals with analysis of the root temperature effect on root hydraulic resistances in cucumber and figleaf gourd root systems.

MATERIALS AND METHODS

Plant materials

Cucumber plants (*Cucumis sativus* L. cv Chojitsu-Ochiai) and figleaf gourd plants (*Cucurbita ficifolia* B. cv Kurodane) were used. The plants were grown in fully aerated hydroponics at an air temperature of 23°C and a relative humidity of 70% in a phytotron glass room. The whole root system of the 3 leaf stage plant of healthy growth was used as a specimen. The dry weight of the whole root system used was 0.12±0.03 g in cucumber plant and 0.14±0.03 g in figleaf gourd plant (there was no significant difference between those two species at 5% level).

Measurement system

Figure 1 shows the schematic diagram of the system for the root temperature control and the measurement of root hydraulic resistance in a detached root system. Root temperature in a stainless steel pot (3.7 l) was controlled from 8 to 32(±0.1)°C by a water bath method: The pot was placed in the water bath where temperature-controlled water was circulated, and the upper surface of the pot was covered with heat insulating materials of styrofoam. The pot was filled with aerated nutrient solution which was slowly stirred.

The root system of a material plant was detached at the stem base in $CaCl_2$ solution of 20 mmol l^{-1}. The proximal end (cut end of the root system) was connected to a glass tube, and the tube was sealed with silicone rubber. The root system was set in the pot, and the pot was air-tightened with rubber stoppers and

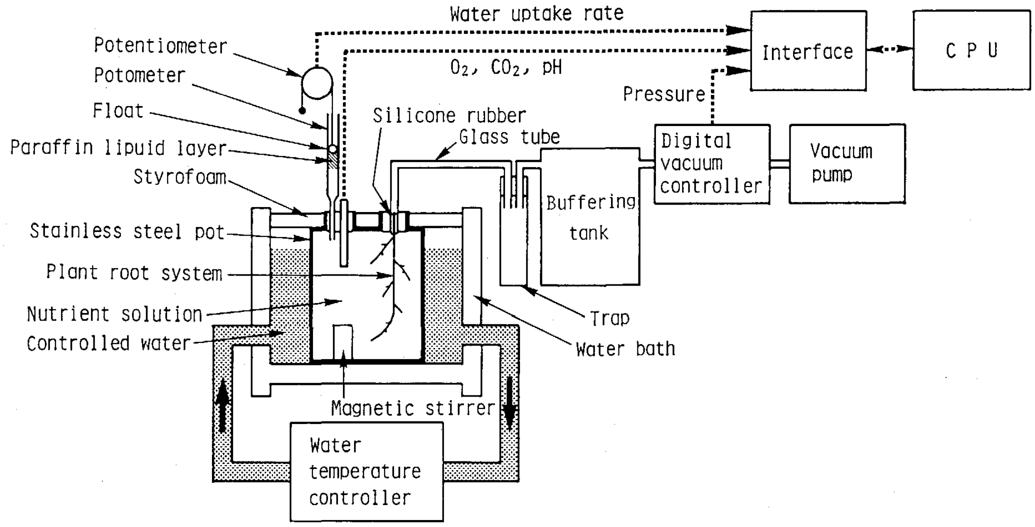

Fig. 1. Schematic diagram of an air-tightened hydroponic system for the measurement of total root resistance in a whole root system where the suction is applied.

silicone grease. The glass tube was connected to a digital vacuum controller (VC-20S, Okano Works Ltd.) with a vacuum pump through a water trap and a buffering tank. The pressure at the proximal end was controlled at an external atmospheric pressure minus 80 kPa, so that the suction of 80 kPa was applied to the root system.

Water uptake rate in the detached root system was measured by a potometer, where the decrease of the solution was detected by a float connected to a potentiometer (The solution surface in the potometer was sealed with paraffin liquid layer to prevent diffusion of air into the solution). A polarographic O_2-meter (UD-1, Central Kagaku Co., Ltd.), a potentiometric electrode CO_2-meter (CGP-1, Toa Electronics Ltd.), and pH-meter (HM-7E, Toa Electronics Ltd.) were employed for on-line measurements of dissolved O_2 and CO_2 concentrations. The respective sensor signals were transmitted to CPU through interfaces.

Measurement of CO_2 concentration

Dissolved CO_2 is composed of unionized CO_2 (CO_2 and H_2CO_3) and ionized CO_2 (HCO_3^- and CO_3^{2-}) which are in equilibrium, as described by Helder (*8*). The molarity of total inorganic carbon (ΣCO_2) can be obtained by summing the molarities of unionized CO_2 and ionized CO_2 as follows,

$$[\Sigma CO_2] = [CO_2+H_2CO_3]+[HCO_3^-]+[CO_3^{2-}] \tag{1}$$

The molarity ($[CO_2+H_2CO_3]$) of unionized CO_2 was directly measured by the CO_2-meter, and the molarity ($[HCO_3^-]+[CO_3^{2-}]$) of ionized CO_2 was evaluated by using measured $[CO_2+H_2CO_3]$ and pH from Henderson-Hasselbach equations:

$$\log [HCO_3^-] = \log [CO_2+H_2CO_3]+\mathrm{pH}+\log K_{a1} \tag{2}$$

$$\log [CO_3^{2-}] = \log [HCO_3^-]+\mathrm{pH}+\log K_{a2} \tag{3}$$

where K_{a1} and K_{a2} are equilibrium constants for the ionization of dissolved CO_2 in the solution, and can be calculated at a given temperature of T(K) by Eqs. (4) and (5):

$$\ln K_{a1} = -14554.21T^{-1}+290.9097-45.0575 \ln T \tag{4}$$

$$\ln K_{a2} = -11843.79T^{-1}+207.6548-33.6485 \ln T \tag{5}$$

Thus, the CO_2 concentration was evaluated as the molarity of total inorganic carbon.

Calculation of total root resistance

The hydraulic resistance in a root system was defined as total root resistance (total hydraulic resistance per whole root system) in this experiment. The total root resistance can be expressed by

$$R = \frac{\Psi_1-\Psi_2}{F} \tag{6}$$

where R is the total root resistance, Ψ_1 is the water potential of the nutrient solution,

Ψ_2 is the water potential at the proximal end of the root system, and F is the water uptake rate. Ψ_1 is composed of the external atmospheric pressure (Ψ_{p1}) and the osmotic potential of the nutrient solution ($\Psi_{\pi 1}$), and Ψ_2 is composed of the pressure at the proximal end (Ψ_{p2}) and the osmotic potential of the xylem sap ($\Psi_{\pi 2}$). Therefore, R can be rewritten by using the pressure potential difference ($\Delta\Psi_p$) and the osmotic potential difference ($\Delta\Psi_\pi$) as follows,

$$R = \frac{(\Psi_{p1}+\Psi_{\pi 1})-(\Psi_{p2}+\Psi_{\pi 2})}{F} = \frac{\Delta\Psi_p+\Delta\Psi_\pi}{F} \tag{7}$$

For evaluation of osmotic potential, xylem sap exuded from root systems was sampled, and the osmotic potential was measured by the method of Campbell *et al.* (*3*): The sample was placed in a sample chamber of a thermocouple psychrometer (HR-33T, Wescor Inc.). The measurement was performed after 30 min of water vapor equilibrium in the sample chamber. The output of the thermocouple was converted to osmotic potential by using NaCl standards of known osmotic potentials. The osmotic potential of the nutrient solution was also measured in the same manner.

Thus, measured osmotic potentials of the nutrient solution ($\Psi_{\pi 1} = 80$ kPa) and of xylem sap ($\Psi_{\pi 2} = 100 \pm 10$ kPa) were obtained. Therefore, the osmotic potential difference ($\Delta\Psi_\pi$) was 20 kPa. So that, the total root resistance was calculated from Eq. (7) by using the water potential difference ($\Delta\Psi_p+\Delta\Psi_\pi$) of 100 kPa and measured water uptake rate (F).

RESULTS AND DISCUSSION

In general, hydraulic conductance and resistance in roots have been calculated in detached roots under hydrostatic pressure of 200 to 500 kPa applied to external root medium in a pressure chamber, in order to obtain the amount of water flow in intact roots of a transpiring plant (*5*, *6*, *14*). However, the high pressure may influence the hydraulic properties of roots grown at normal pressure (*10*, *16–18*). In this experiment, the suction of 80 kPa, which was applied to the proximal end of the detached root system, was used for the measurement of the total root resistance.

Figure 2 shows an example of the time course patterns of O_2 and CO_2 concentrations and water uptake rate in the cucumber root system, where the pressure was applied to the proximal end at the root temperature of 24°C. At the start of the suction (t=0 min), O_2 concentration was 0.24 ± 0.02 mmol l^{-1} and CO_2 concentration was 0.02 ± 0.003 mmol l^{-1}. During 120 min, O_2 and CO_2 concentrations became 0.17 mmol l^{-1} and 0.04 mmol l^{-1}, respectively, even when the concentrations changed most rapidly at the highest root temperature of 32°C. These small changes in O_2 and CO_2 concentrations did not influence the water uptake (*20*). Just after the start of suction (t=0 to 15 min), the water uptake rate rapidly increased, and thereafter became steady state. Therefore, the means of the measured values from 30 to 90 min were used as F in Eq. (7) for the evaluation of the total root resistance.

Figure 3 shows the distributions of water uptake rates (a), O_2 decrease rates

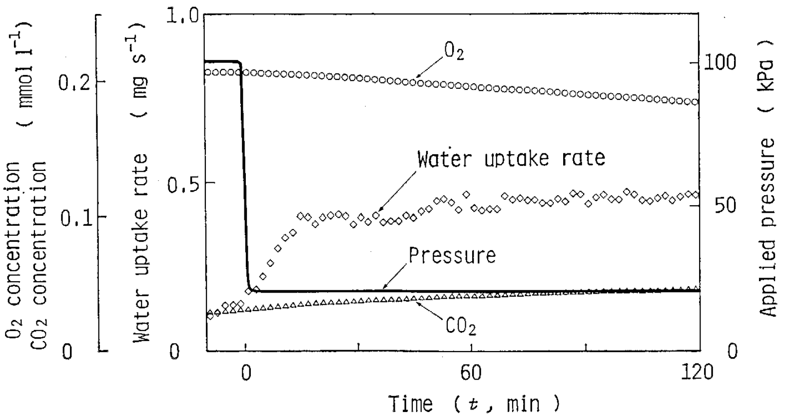

Fig. 2. Time course patterns of water uptake rate (◇) in a cucumber root system at the pressure (——) applied to the proximal end of the root system, O_2 concentration (○), and CO_2 concentration (△) in nutrient solution at 24°C in the air-tightened hydroponic system.

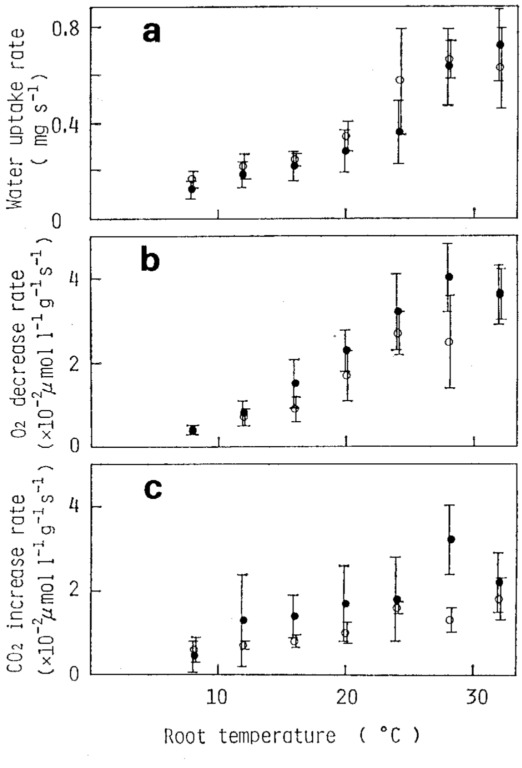

Fig. 3. Distributions of water uptake rates (a), O_2 decrease rates (b) and CO_2 increase rates (c) on root temperature in cucumber (●) and figleaf gourd (○) root systems under the suction of 80 kPa, where the means of values measured in 6 plants are plotted with 95% confidence intervals.

(b), and CO_2 increase rates (c) on root temperature in cucumber and figleaf gourd root systems. Water uptake rate was clearly reduced at lower root temperatures in those two species. The O_2 decrease rate and the CO_2 increase rate were also reduced at lower root temperatures in those two species. This result agreed with

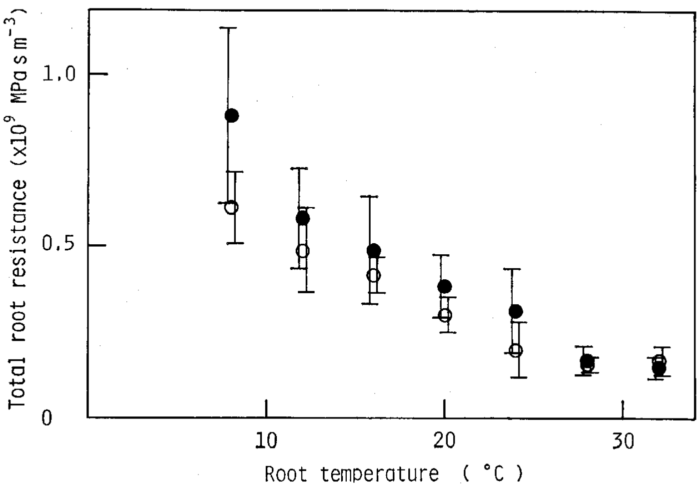

Fig. 4. Distributions of total root resistances on root temperature in cucumber (●) and figleaf gourd (○) root systems at the water potential difference of 100 kPa, where the means of values measured in 6 plants of respective species are plotted with 95% confidence intervals.

the characteristics observed in the root gas exchange of intact cucumber plant as reported in previous paper (*20*).

Figure 4 shows distributions of the total root resistances on root temperature. The total root resistances distributed in a region of about 0.2×10^9 to about 1.0×10^9 MPa s m^{-3} in those two species: The total root resistances became higher at lower root temperatures and reduced to about 0.2×10^9 MPa s m^{-3} at higher root temperatures. This fact suggests that decrease in water uptake at lower root temperatures (Fig. 3) is due to increase in the total root resistance at lower root temperatures. The total root resistance consists of the radial resistance from the external solution to the root xylem and the axial resistance in the root xylem (*7*). Nagano and Ishida (*15*) have reported that the radial resistance (absorptive resistance) constitutes 80–85% of the total root resistance in a soybean root system. Therefore, the total root resistance was influenced by the root temperature mainly through the radial resistance, and it could be conceivable that the temperature effect on total root resistance is associated with the permiability in the root cell membrane in response to the root temperature.

Furthermore, species specific difference in total root resistance was found between those two species at lower root temperatures: At the root temperature of 8°C, the total root resistance in the cucumber root system was higher than that in the figleaf gourd root system, and the difference in total root resistance between those two species was significant at 5% level. At higher root temperatures, however, the total root resistances were kept lower, and any appreciable differences were not found between those two species. In general, the cucumber plant grafted on the stock of the figleaf gourd plant has been used for cucumber production, because this grafted plant becomes relatively tolerant of lower soil temperatures in the growing process (*19*). Eguchi and Koutaki (*4*) have found the leaf transpiration in figleaf gourd and the grafted cucumber plants is more active than that in cucumber plant at the root temperatures lower than 10°C. From these facts, the low temperature tolerance in figleaf gourd plant could be considered to be brought by lower hydraulic resistance in a root system at lower root temperatures.

REFERENCES

1. Boyer J. S. (1971) Resistances to water transport in soybean, bean, and sunflower. *Crop Sci.* **11**, 403–407.
2. Boyer J. S. (1985) Water transport. *Ann. Rev. Plant Physiol.* **36**, 473–516.
3. Campbell E. C., Campbell G. S. and Barlow W. K. (1973) A dewpoint hygrometer for water potential measurement. *Agric. Meteorol.* **12**, 113–121.
4. Eguchi H. and Koutaki M. (1986) Analysis of soil temperature effect on transpiration by leaf heat balance in cucumber, cucurbit and their grafted plants. *Biotronics* **15**, 45–54.
5. Fiscus E. L. (1975) The interaction between osmotic- and pressure-induced water flow in plant roots. *Plant Physiol.* **55**, 917–922.
6. Fiscus E. L. (1977) Determination of hydraulic and osmotic properties of soybean root systems. *Plant Physiol.* **59**, 1013–1020.
7. Frensch J. and Steudle E. (1989) Axial and radial hydraulic resistance to roots of maize (*Zea mays* L.). *Plant Physiol.* **91**, 719–726.
8. Helder R. J. (1988) A quantitative approach to the inorganic carbon system in aqueous media used in biological research: Dilute solutions isolated from the atmosphere. *Plant, Cell Environ.* **11**, 211–230.
9. Kaufmann M. R. (1975) Leaf water stress in engelmann spruce. Influence of the root and shoot environments. *Plant Physiol.* **56**, 841–844.
10. Koide R. (1985) The nature and location of variable hydraulic resistance in *Helianthus annus* L. (sunflower). *J. Exp. Bot.* **36**, 1430–1440.
11. Kramer P. J. (1940) Root resistance as a cause of decreased water absorption by plants at low temperatures. *Plant Physiol.* **15**, 63–79.
12. Kramer P. J. (1942) Species differences with respect to water absorption at low soil temperatures. *Am. J. Bot.* **29**, 828–832.
13. Kramer P. J. (1983) Factors affecting the absorption of water. Pages 235–261 *in Water Relations of Plants*. Academic Press, New York.
14. Markhart A. H., Fiscus E. L., Naylor A. W. and Kramer P. J. (1979) Effect of temperature on water and ion transport in soybean and broccoli systems. *Plant Physiol.* **64**, 83–87.
15. Nagano T. and Ishida T. (1984) Internal Plant-water-status and its control. III. The root resistance to water movement through the soybean root. *J. Agr. Met.* **40**, 229–233 (in Japanese with English summary).
16. Nobel P. S., Schulte P. J., and North G. B. (1990) Water influx characteristics and hydraulic conductivity for roots of *Agave deserti* Engelm. *J. Exp. Bot.* **41**, 409–415.
17. Salim M. and Pitman M. G. (1984) Pressure-induced water and solute flow through plant roots. *J. Exp. Bot.* **35**, 869–881.
18. Salim M. and Pitman M. G. (1984) Water and solute flow through mung bean roots under applied pressure. *Physiol. Plant.* **61**, 263–270.
19. Tachibana S. (1982) Comparison of effects of root temperature on the growth and mineral nutrition of cucumber cultivars and figleaf gourd. *J. Jpn. Soc. Hort. Sci.* **51**, 299–308.
20. Yoshida S. and Eguchi H. (1989) Effect of root temperature on gas exchange and water uptake in intact roots of cucumber plants (*Cucumis sativus* L.). *Biotronics* **18**, 15–21.