EFFECT OF ROOT TEMPERATURE ON GAS EXCHANGE AND WATER UPTAKE IN INTACT ROOTS OF CUCUMBER PLANTS (CUCUMIS SATIVUS L.) IN HYDROPONICS

Yoshida, Satoshi
Biotron Institute Kyushu University

Eguchi, Hiromi
Biotron Institute Kyushu University

http://hdl.handle.net/2324/8149
EFFECT OF ROOT TEMPERATURE ON GAS EXCHANGE AND WATER UPTAKE IN INTACT ROOTS OF CUCUMBER PLANTS (*CUCUMIS SATIVUS* L.) IN HYDROPONICS

S. YOSHIDA and H. EGUCHI

*Biotron Institute, Kyushu University 12, Fukuoka 812, Japan*

(Received August 19, 1989; accepted September 5, 1989)

YOSHIDA S. and EGUCHI H. *Effect of root temperature on gas exchange and water uptake in intact roots of cucumber plants (*Cucumis sativus* L.) in hydroponics.* BIOTRONICS 18, 15–21, 1989. Dissolved O$_2$ and CO$_2$ concentrations in nutrient solution and water uptake rate in intact cucumber roots were examined at different root temperatures of 8 to 28°C by using the on-line measurements in an air-tightened hydroponic system under the controlled environment. The root temperature effects on gas exchange and water uptake in roots were found in the sigmoidal pattern, and the patterns of the gas exchange and the water uptake on root temperature appeared almost parallel with each other: The responses decreased with root temperatures lower than 12°C and increased with root temperatures higher than 16°C.

**Key words:** *Cucumis sativus* L.; cucumber plant; root temperature; gas exchange; water uptake rate; hydroponics; O$_2$ concentration; CO$_2$ concentration.

INTRODUCTION

The plant growth and the physiological activities are affected by rhizosphere environment through various root functions (2, 4–7, 10, 17, 21, 22). The basal environmental factors are soil moisture, soil gaseous composition, nutrition and root temperature (12). Root temperature is known to be essential for water uptake and gas exchange in roots. Several workers have reported the root temperature effect on water relation in plants and root gas exchange (3, 8, 13–15, 18–20). In particular, Andersen *et al.* (1) and Everard and Drew (9) have reported that water relation in plants are associated with root gas exchange.

The present paper deals with analysis of the root temperature effects on water uptake and gas exchange in intact roots by on-line measurements in an air-tightened hydroponic system, aiming at understanding of interrelations among root gas exchange, root water uptake and root temperature.

MATERIALS AND METHODS

*Hydroponic and measurement systems*

The air-tightened hydroponic system which has been reported in the previous
paper (23) was used for root temperature control and for on-line measurements of water uptake rate and gas exchange in intact roots. The hydroponic system was installed in a growth chamber (16) where air temperature and relative humidity were controlled in artificial light. The solution temperature in a stainless steel pot (3.7 litre) was controlled by a water bath method. A polarographic dissolved O₂-meter (UD-1, Central Kagaku Co., Ltd.), a potentiometric membrane electrode CO₂-meter (CGP-1, Toa Electronics Ltd.) and a pH-meter (HM-7E, Toa Electronics Ltd.) were employed for the on-line measurements of dissolved O₂ and CO₂ concentrations in the solution. The solution was slowly stirred for the measurements. The sensors were fixed in the pot by using rubber corks with silicone grease. Water uptake rate in roots was measured automatically by a potometer: The surface level of nutrient solution in the potometer was detected by a float which was connected to a potentiometer, where the solution surface of the potometer was sealed with paraffin liquid layer to prevent diffusion of air into the solution. The respective sensor signals were transmitted to CPU through interfaces.

**Plant material and experimental condition**

Cucumber plants (*Cucumis sativus* L. “Chojitsu-Ochiai”) were used in this experiment. The plants were grown in fully aerated hydroponics at an air temperature of 23°C, a relative humidity of 70% and a light intensity of 250 μmol m⁻² s⁻¹ (metal halide lamps; Yoko lamp, DR400, Toshiba Corp.) in photoperiod of 12 h. The 3rd leaf stage plant was transplanted to the air-tightened hydroponic system after keeping the plant under the respective experimental root temperatures for 18 h in order to adapt the plant to the experimental conditions. The water uptake and the gas exchange in roots were measured for 4 days under the condition of an air temperature of 25°C, a relative humidity of 40% and continuous light with an intensity of 200 μmol m⁻² s⁻¹ (flourescent lamps; FLR110-EHW/A, Toshiba Corp.) in the growth chamber. The root temperatures were controlled in a region of 8 to 28±0.1°C. The pH in the solution distributed from 4.5 to 6.5. After the measurements for 4 days, the dry weight of the detached whole roots was measured.

**Analysis of CO₂ concentration**

Dissolved CO₂ is hydrated and subsequently ionized, and the components of inorganic carbon, which are CO₂, H₂CO₃, HCO₃⁻ and CO₃²⁻, are in equilibrium in the solution, as described by Helder (11). The relationships between unionized and ionized components of the inorganic carbon in the solution are represented by Henderson-Hasselbach equations as follows,

\[
\begin{align*}
\log \frac{[\text{HCO}_3^-]}{[\text{CO}_2+\text{H}_2\text{CO}_3]} &= \text{pH} - pK_a1 \\
\log \frac{[\text{CO}_3^{2-}]}{[\text{HCO}_3^-]} &= \text{pH} - pK_a2
\end{align*}
\]

(1)

where \(K_a1\) and \(K_a2\) are equilibrium constants for the ionization of dissolved CO₂ in the solution, \(pK_{a1} = -\log K_{a1}\), and \(pK_{a2} = -\log K_{a2}\). The equilibrium constants at a given temperature of \(T(K)\) can be calculated by Eqs. (2) and (3):

\[
\begin{align*}
\ln K_{a1} &= -14554.21 T^{-1} + 290.9097 - 45.0575 \ln T \quad (2) \\
\ln K_{a2} &= -11843.79 T^{-1} + 207.6548 - 33.6485 \ln T \quad (3)
\end{align*}
\]

*BIOTRONICS*
The molarity of total inorganic carbon is obtained from summing respective molarities of the unionized components (CO$_2$ and H$_2$CO$_3$) and the ionized components (HCO$_3^-$ and CO$_3^{2-}$). The molarity of unionized components can be measured by the CO$_2$ electrode, and the molarities of ionized components were calculated from respective Eqs. (4) and (5) by using measured pH and measured molarities of the unionized components.

$$\log [\text{HCO}_3^-] = \log [\text{CO}_2 + \text{H}_2\text{CO}_3] + \text{pH} - \text{pK}_a$$

$$\log [\text{CO}_3^{2-}] = \log [\text{HCO}_3^-] + \text{pH} - \text{pK}_{a2}$$

Thus, CO$_2$ concentration was evaluated in this experiment by using the molarity of the total inorganic carbon.

RESULTS AND DISCUSSION

Dissolved O$_2$ and CO$_2$ concentrations in nutrient solution and water uptake rate in roots were measured at different root temperatures. Figure 1 shows examples of the time course patterns of O$_2$ and CO$_2$ concentrations and water uptake rate at respective root temperatures of 12, 20 and 28°C. The O$_2$ concentration, which was initially 0.25±0.01 mmol l$^{-1}$, decreased to 0.01 mmol l$^{-1}$ in 38 h at 12°C, in 18 h at 20°C and in 8 h at 28°C (Fig. 1a). The velocity of the O$_2$ decrease was enhanced with the higher root temperatures. On the other hand, the initial CO$_2$ concentration was 0.06±0.01 mmol l$^{-1}$. At the root temperature of 28°C, the CO$_2$ concentration reached to about 3.1 mmol l$^{-1}$ in 80 h, and thereafter it was kept steady-state. At the root temperatures of 12 and 20°C, the CO$_2$ concentration continued to increase in the time course of 96 h (Fig. 1b). The velocity of the CO$_2$ increase was enhanced with higher root temperatures as well as the velocity of the O$_2$ decrease. Thus, CO$_2$ concentration continued to increase even after the time when O$_2$ concentration decreased to 0.01 mmol l$^{-1}$. In the previous paper, the same results have been obtained, and it has been supposed that gas exchange in intact roots relates to leaf gas exchange through stomatal openings (23). From these results, it became clear that the CO$_2$ release in roots can be caused even in the O$_2$ deficit solution. So, it was difficult to calculate the root respiratory quotient from the balance of O$_2$ uptake and CO$_2$ release in the nutrient solution.

Water uptake rate at the root temperature of 12°C was kept remarkably lower than those at the higher root temperatures: The water uptake rate at the root temperatures of 20 and 28°C became higher during 30 h after the start of the measurements and gradually decreased (Fig. 1c). Thus, it was obvious that both gas exchange and water uptake in roots are inhibited with lower root temperatures and are enhanced with higher root temperatures.

To examine root temperature effect on gas exchange and water uptake in roots, O$_2$ decrease rate, CO$_2$ increase rate (per root dry weight) and water uptake rate (per plant) were evaluated by using the mean of the measured values in 4 plants in the root temperature region of 8 to 28°C. Figure 2 shows the distribution of O$_2$ decrease rates ($\mu$mol l$^{-1}$ g$^{-1}$ s$^{-1}$) on root temperature. The root temperature effect on O$_2$ decrease rate was found in a sigmoidal pattern: The O$_2$ decrease rate...
appeared lower at the root temperatures lower than 12°C and was saturated at the root temperatures higher than 16°C. Figure 3 shows the distribution of CO₂ increase rates ($\mu$mol $l^{-1}$ g $^{-1}$ s $^{-1}$) on root temperature. The CO₂ increase rate became lower at the root temperatures lower than 16°C and was saturated at the root temperatures higher than 20°C. Thus, almost similar patterns were found in both O₂ decrease rate and CO₂ increase rate. In detail of the patterns, however, there was small difference in root temperature effect between O₂ decrease rate and CO₂ increase rate: The O₂ decrease rate was saturated at 16°C, while the CO₂ increase rate was saturated at 20°C.

Figure 4 shows the distribution of water uptake rates on root temperature. The root temperature effect on water uptake rate was also found in the sigmoidal pattern: Water uptake rate was lower at the root temperatures lower than 12°C and was
kept higher and almost constant at the root temperatures higher than 16°C.

These sigmoidal patterns of O₂ decrease rates, CO₂ increase rates and water uptake rates on root temperature agreed with the results that Clarkson et al. (3), Macduff et al. (14), Markhart et al. (15) and Running and Reid (18) have obtained.
in uptake rates of water and nutrition in relation to the root temperature. Eguchi and Koutaki (8) have reported the similar effect of root temperature on leaf transpiration.

Thus, the gas exchange and the water uptake in roots clearly responded to the root temperature, and their response curves on root temperature appeared almost parallel with each other in the sigmoidal pattern where the response rates decreased at root temperatures lower than 12°C and increased at root temperatures higher than 16°C in cucumber plants. This event may help to understand the dependence of water relation in plants on the root temperature.

REFERENCES

BIOTRONICS


