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Study on Root Absorption Responding to Environmental Stress by Using Hydroponic Systems

By

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S u m m a r y

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This study deals with effects of high temperature stress and salt stress on root physiological functions by using the system newly developed for measurements of water and nutrients uptake by roots. Dynamic and simultaneous evaluation of rates of water and nutrients uptake by roots was enabled in the hydroponic system. Rates of water and nutrients uptake by roots were evaluated simultaneously on the basis of time courses analyses of water balance and nutrients balance in the system. Furthermore, the simultaneous evaluation of water and nutrients uptake rates enabled estimation of concentration of each nutrient in xylem sap.

In the short-term (one or two weeks), the high root temperature activated water and nutrients uptake through decrease in water viscosity, and the salt stress significantly depressed water uptake rate through decrease in osmotic potential of the nutrient solution, which retarded mass flow in the nutrients uptake. On the other hand, the long-term (several weeks) of the high root temperature depressed water and nutrients uptake and resulted in growth depression and browning in roots. The long-term effects of the high root temperature were considered to relate to the reduced oxygen solubility and the increased enzymatic oxidization of phenolic compounds in root epidermal and cortex tissues. Thus, the short-term effects of the high root temperature and the salt stress were brought mainly through the physical processes, and the long-term effects of the high root temperature were brought through the physiological processes.

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Introduction

For plant production under global environmental changes, information about physiological functions of intact roots under environmental stresses caused by elevated temperature, water deficit, salinity and pollution of soil and water is essential. However, there have been difficulties in measurement of physiological functions of intact roots in the plant production systems.

The root systems perform two primary functions, one is the uptake of water and nutrients and the other is the anchorage to the ground (FITTER 1996). It has been well known that the lower root temperature decreased root water uptake by increasing root hydraulic resistance, which is accompanied by decrease in nutrient uptake. However, there has been poor information about the effects of high temperature on water and nutrients uptake (KRAMER & BOYER 1995).

Roots, as the absorbing organs, play a critical role in determining plant and ecosystem responses to various facets of global change, but studies of root responses to global change has been often focused on root growth and morphological characteristics, seldom addressing changes in physiological functions (BASSRIRAD 2000). This study deals with effects of high temperature stress and salt stress on root physiological functions by using the system newly developed for measurements of water and nutrients uptake in the plant production system.

Material and Methods

System for evaluation root absorption

The NFT (i.e. Nutrient Film Technique) system was newly developed for dynamic and simultaneous evaluations of water and nutrients uptake rates by intact roots in a greenhouse (YASUTAKE & al. 2004). Figure 1 shows a schematic diagram of the system. The system is composed of a circulating unit (an NFT bed, a reservoir tank, etc.) and a water supply unit (a water supply tank, a solenoid valve, a supply line etc.) for controlling the nutrient solution. A water level sensor is installed in the reservoir tank to detect decrease in volume of the nutrient solution caused by water uptake by plants. The circulation unit is automatically replenished with fresh nutrient solution from the supply unit by the on-off action of the solenoid valve which is manipulated according to a feedback signal from the water level sensor. Therefore, the rate of water uptake (Q_w, L d^{-1}) by roots can be evaluated from the supply volume (SV, mL) and the frequency (f ; h^{-1}) of the on-off action. Furthermore, integrated water uptake by roots for a given period can be measured by the integrated flow meter (IFMs) on the supply line. Evaporation loss from the nutrient solution in the NFT bed and the reservoir tank was inhibited completely by covering the bed and the tank with a plastic film. Rates of nutrients uptake (Q_M, g d^{-1}) by roots can be also evaluated based on the quantity of nutrients supplied with the replenished fresh nutrient solution and the change in concentration of nutrients in the circulation unit. The nutrient solution is sampled twice a day, and changes in nutrients concentrations were measured by using the soil-plant chemical analyzer (SPCA-6210, Shimadzu, Kyoto, Japan). The simultaneous evaluation of water and nutrients uptake rates enabled evaluation of nutrients concentrations in xylem sap ([M]xy, g L^{-1}) by dividing the respective nutrients uptake rates by the water uptake rate.

Plant materials

Tomato plants (*Lycopersicon esculentum* Mill.cv.Hausu Momotaro) were used for experiments with four NFT beds in the greenhouse. Seeds of tomato plants were sown in cell trays filled with vermiculite in a growth chamber. On each NFT bed, 25 tomato plants were transplanted

and grown with the standard nutrient solution with an electric conductivity (*EC*) of 1.0 dS m^{-1} at the optimum temperature of 22 °C. Five weeks later, the solution temperature in the two beds was changed from 22 °C to 35 °C for the high root temperature stress treatment. Simultaneously, the salt stress treatment was started in the two beds with the respective solution temperature of 35 °C and 22 °C by increasing *EC* of the nutrient solution from 1.0 dS m^{-1} to 15.0 dS m^{-1}. For the salt stress treatment, the deep seawater was applied to the standard nutrient solution. The applied deep seawater is enriched in not only sodium but other minerals such as calcium, magnesium and potassium and expected to be useful for production of high quality tomatoes with high sugar and minerals concentrations. The short-term (one or two weeks) effects of the high root temperature treatment and the salt stress treatment and the long-term (four weeks) effect of the high root temperature treatment were analyzed.

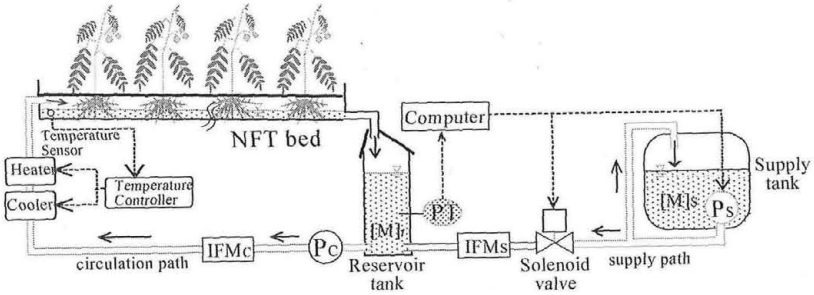

Fig. 1. Schematic diagram of the NFT system developed for dynamic and simultaneous evaluation of water and nutrients uptake rates by roots of plant population. The system is composed of the circulation unit (an NFT bed, a reservoir tank, a water pump and a circulation path, etc.) and the supply unit (a supply tank, a solenoid valve, a water pump and a supply path, etc.) for controlling the nutrient solution: IFM_c and IFM_s, integrated flow meters on the circulation and supply paths, respectively; $[M]_s$, concentration of nutrient *M* in the supply tank; $[M]_t$, concentration of nutrient in the circulation unit at time *t*; PT, pressure transmitter for measurement water level in the reservoir tank; Pc, water pump for circulating the nutrient solution between the reservoir tank and the NFT bed; Ps, water pump for supplying nutrient solution from the supply tank to the reservoir tank; Solid arrows, flow of nutrient solution; broken arrows, flow of electric signals.

Results and Discussion

Fig. 2 shows weekly changes in rates of water uptake (Q_W), nitrate uptake (Q_{NO3}), sodium uptake (Q_{Na}) and calcium uptake (Q_{Ca}) at different root temperatures of 35 °C and 22 °C under the no-salt stress (EC = 1.0 dS m^{-1}) and the salt stress (EC = 15 dS m^{-1}) conditions. Under the no-salt stress, uptake rates of water and nutrients of NO_3^- and Ca^{2+} were increased just after the start of the high root temperature treatment, but one week later, uptake rates of water and nutrients were depressed (Fig. 2 A, B and D). On the other hand, Na^+ uptake was always depressed at the lower rates, and effects of the high root temperature was not clearly found in the Na^+ uptake (Fig. 2C). The high root temperature enhanced water uptake in roots through decrease in water viscosity which brought the lower resistance to water transport (KRAMER & BOYER 1995), and this enhanced water uptake

result in the increased mass flow in nutrients uptake. Under the salt stress, uptake rate of water, NO_3^- and Ca^{2+} were decreased (Fig. 2E, F and H), even at the beginning of the high root temperature treatment, but Na^+ uptake rate was increased from the start of the salt stress treatment because of significant rise in Na^+ concentration in the nutrient solution (Fig. 2G). Decrease in osmotic potential of the nutrient solution during the salt stress can be considered to cause the lower uptake rates of water which are accompanied by decrease in mass flow of nutrients (CUERTERO & MUNOZ 1999, MUNNS 2002).

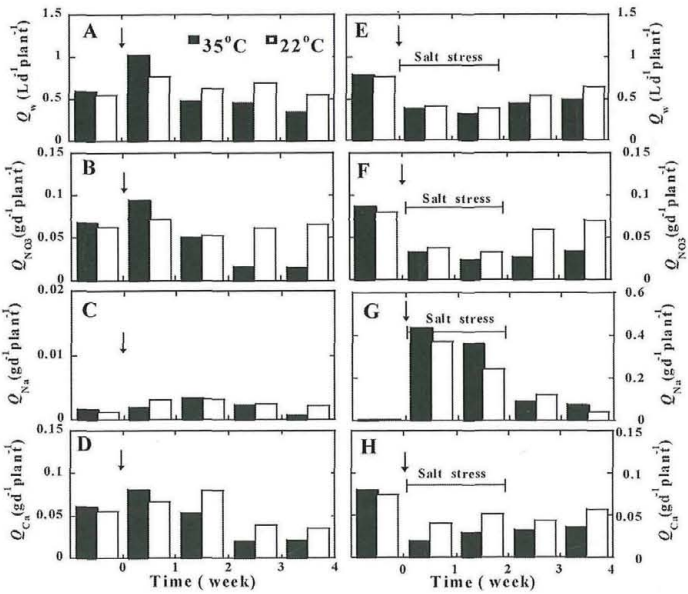

Fig. 2. Weekly changes in rates of water uptake (Q_w), nitrate uptake (Q_{NO3}) , sodium uptake (Q_{Na}) and calcium uptake (Q_{Ca}) at the different root temperatures of 35 °C and 22 °C under the no-salt stress (EC = 1.0 dS m^{-1}) and the salt stress (EC = 15 dS m^{-1}) conditions in the NFT system for five weeks. Arrows indicate the start of the high root temperature (35 °C) treatment.

Fig. 3 shows weekly changes in concentrations of nutrients (NO_3^-, Na^+ and Ca^{2+}) in xylem sap and the nutrient solution of the NFT system at the root temperatures of 35 °C and 22 °C under the no-salt stress and the salt stress conditions. Nutrients concentrations in xylem sap remained almost stable at the optimum temperature. However, these xylem sap concentrations of nutrients except for Na^+ became lower during the long-term treatment with the high root temperature under the no-salt stress and the salt stress conditions (Fig. 3). Comparing with concentrations in the nutrient solution, concentrations of NO_3^- and Ca^{2+} in the xylem sap were higher (Fig. 3). This indicates that the active processes of NO_3^- and Ca^{2+} uptake driven by the transporter and the proton pump also play an important role (WHITE 2001,

GLASS & al. 2002). In the long-term effects of the high temperature under the no-salt stress, NO_3^- and Ca^{2+} concentrations in xylem sap showed the respective decreased patterns, although NO_3^- and Ca^{2+} concentrations in the nutrient solution increased (Fig. 3A). This indicates that the active processes of nitrate and calcium uptake were retarded by the high root temperature. This long-term effect of the high root temperature was not clearly found under the salt stress, because the salt stress significantly depressed nutrients uptake (Fig. 3D, E and F).

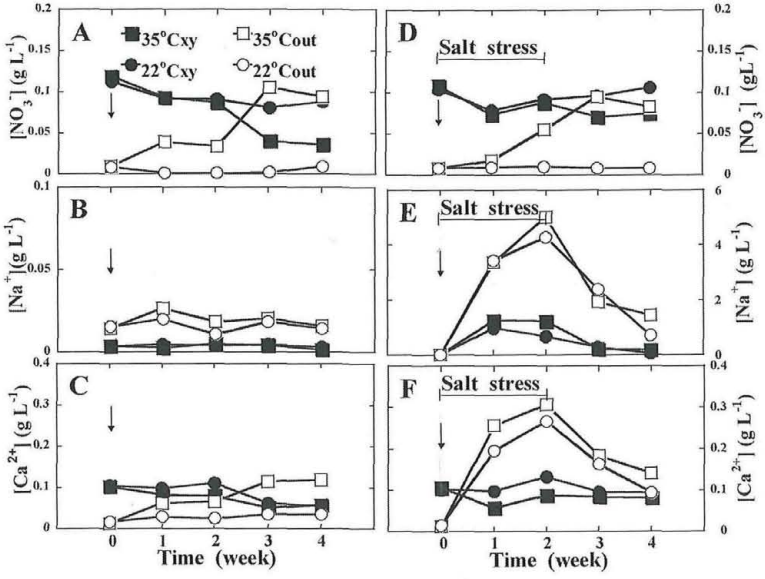

Fig. 3. Weekly changes in nutrients (NO_3^-, Na^+ and Ca^{2+}) concentrations in xylem sap and solution of the NFT system at the different root temperatures of 35 °C and 22 °C under the no-salt stress (EC = 1.0 dS m^{-1}) and the salt stress (EC = 15 dS m^{-1}) conditions in the NFT system for five weeks. Arrows indicate the start of the high root temperature (35 °C) treatment.

Furthermore, growth depression (Table 1) and browning in roots occurred several weeks after the high root temperature treatment. These effects of high root temperature was considered to closely relate to the reduced oxygen solubility and the increased enzymatic oxidization of phenolic compounds that produces brown substance in root epidermal and cortex tissues and causes depression in activity of root physiological functions (HURD 1978, FUKUOKA & ENOMOTO 2001, WEELS & EISSENSTAT 2003). The reduced oxygen solubility and the increased root respiration under the high solution temperature can be estimated to decrease the oxygen concentration around the roots, which can also deteriorate physiological functions, morphology and growth of roots.

Thus, the short-term effects of the high root temperature and the salt stress were brought mainly through the physical processes such as change in water vis-

cosity and changes in osmotic potential and concentration in the nutrient solution. Furthermore, the long-term effects of the high root temperature were brought through the physiological processes such as active transport, respiration, growth and browning in roots.

Table 1. Root dry weight at different root temperatures of 35 °C and 22 °C under the no-salt stress (EC = 1.0 dS m^{-1}) and the salt stress (EC = 15 dS m^{-1}) in the NFT system. Data is average of five plants with standard deviation. Different letters in parentheses to the right of data denote that values were significantly different at $p < 0.05$.

Treatments	Root dry weight (g $plant^{-1}$)
High temperature with no-salt stress	18.06 ± 0.64 (a)
Optimum temperature with no-salt stress	20.88 ± 1.54 (b)
High temperature with salt stress	17.58 ± 0.59 (a)
Optimum temperature with salt stress	20.25 ± 0.88 (b)

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