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TRANSPIRATION RESPONDING TO LIGHT CONDITIONS IN CONTROLLED ENVIRONMENTS—EFFECT OF INFRARED RADIATION*

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EGUCHI H. and KITANO M. *Transpiration responding to light conditions in controlled environments—Effect of infrared radiation.* BIOTRONICS **15**, 37–44, 1986. Transpiration rate (E), leaf conductance (C_L), leaf temperature (T_L) and vapor density difference ($W_L - W_A$) between leaf and air in cucumber plants were examined in a phytotron glass room and a growth chamber under different light conditions. In the phytotron, intensity of solar radiation was variable according to solar altitude and sky conditions, and E, T_L and $W_L - W_A$ in the daytime varied with the intensities of the solar radiation: The respective elevations of E, T_L and $W_L - W_A$ were remarkably higher on a fair day as compared with those on a rainy day. On the other hand, C_L in the daytime was kept almost constant even in variable intensities of solar radiation, and E in the daytime was linearly related to $W_L - W_A$ which was responsible for evaporative demand against the plant. The same effects of the light condition on E, C_L, T_L and $W_L - W_A$ were found in the growth chamber under two different artificial lights (metal halide lamps with heat absorbing filter and without the filter) which were set at equal PPFD but contained different intensities of infrared radiation. These results indicate that infrared radiation affects transpiration mainly through the physical process in vapor diffusion from leaf to air. Thus, the infrared radiation were responsible for the increase in evaporative demand against the plant by raising $W_L - W_A$ which varied with T_L affected directly by the radiation.

Key words: *Cucumis sativus* L.; cucumber; transpiration; leaf conductance; leaf temperature; evaporative demand; solar radiation; artificial light; infrared radiation.

INTRODUCTION

Phytotron glass rooms and artificial light growth chambers are widely used as a tool for analyses of plant responses to the environment (*1, 4, 7–9, 11, 14, 19*), where air temperature and humidity are basal controlled factors. In the phytotron glass room, solar radiation is variable according to the solar altitude and the sky conditions. On the other hand, different kinds of lamps are used in the growth chambers

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and there are remarkable variations in intensity and quality of the artificial lights. In those facilities, various characteristics and aspects of plant growth have been found, and it appears conceivable that the light condition is one of the important factors bringing about the differences in plant growth under the controlled environment (*2, 3, 6, 10, 13, 15, 17, 18, 21–23*).

The present paper deals with examination of transpiration in cucumber plants as affected by the lights in a phytotron glass room and a growth chamber.

MATERIAL AND METHODS

Cucumber plants (*Cucumis sativus* L. var. Hort. Chojitsu-Ochiai) were used in the experiments. The plants were potted in Vermiculite® moistened with nutrient solution and grown at air temperature of 23°C and relative humidity of 70% in a phototron glass room. In the intact whole plant at 5 leaves stage, diurnal variations of transpiration rate (E, mg cm^{-2} min^{-1}), leaf conductance (C_L, cm s^{-1}), leaf temperature (T_L, °C), and vapor density difference ($W_L - W_A$, g m^{-3}) between leaf and air were examined at air temperature of 23°C and relative humidity of 70% in the phytotron glass room and the artificial light growth chamber, where controlled air flowed up from the perforated floor with a velocity of 0.3 m s^{-1}. E was measured by weighing the plant and pot in which the pot surface was sealed with polyethylene film to prevent the evaporation. For measuring T_L, T-thermocouples (ϕ 0.1 mm) were inserted into the intact 3rd leaf fixed horizontally. $W_L - W_A$ was calculated by considering that the intercellular space in the leaf was saturated with water vapor. $W_L - W_A$ is responsible for transpiration rate as expressed by Eq. (1), and C_L can be calculated by Eq. (2):

$$E = \frac{6\times 10^{-2}(W_L - W_A)}{r_L + r_A} \tag{1}$$

$$C_L = \frac{1}{r_L + r_A} = \frac{E}{6\times 10^{-2}(W_L - W_A)} \tag{2}$$

where W_L, vapor density in the intercellular space of leaf (g m^{-3}); W_A, vapor density of ambient air (g m^{-3}); r_L, leaf (stomatal and cuticular) resistance to vapor diffusion (s cm^{-1}); r_A, boundary layer resistance to vapor diffusion (s cm^{-1}). Environmental factors of short wave radiant flux density (R_S, mW cm^{-2}), ambient air temperature and relative humidity were measured by Eppley pyranometer, T-thermocouple and electric capacitance meter (HMP15, Vaisala, Oy), respectively.

RESULTS AND DISCUSSION

Phytotron glass room

Figure 1 shows diurnal variations of E, C_L, T_L and $W_L - W_A$ in relation to R_S of solar radiation at air temperature of 23°C and relative humidity of 70% in the phytotron glass room on a fair day. E, T_L and $W_L - W_A$ were almost constant in the nighttime. However in the daytime they varied with R_S at higher elevations and reached to their maximum at about 14: 00: E at its maximum was about 10-fold higher than that in the nighttime. On the other hand, C_L started to increase before the sunrise and was kept at almost constant elevation of 0.45 cm s^{-1} even under variation of R_S in the daytime (7:00–16:00), and decreased before the sunset. Thus, the increase of stomatal aperture seems to be saturated already under lower light intensity at about 7: 00. That is, r_L in Eq. (1) was almost constant in the daytime (7: 00–16: 00) in addition to r_A. From this fact and Eq. (1), it could be suggested that the variation of E in the daytime depended on $W_L - W_A$.

Figure 2 shows diurnal variations of E, C_L, T_L and $W_L - W_A$ in relation to R_S in the phytotron glass room on a rainy day. Patterns of R_S, E, T_L and $W_L - W_A$ in the daytime were remarkably different from those on the fair day. R_S was extremely lower as compared with that on the fair day. E, T_L and $W_L - W_A$ varied with R_S and was kept at the elevations lower than those on the fair day: E in the daytime on the rainy day was about one third of that on the fair day. On the other hand, patterns of C_L was approximately the same as that on the fair day, where C_L started to increase before the sunrise and was kept at almost the same elevation (0.45 cm s^{-1}) as that in the daytime (7: 00–16: 00) on the fair day.

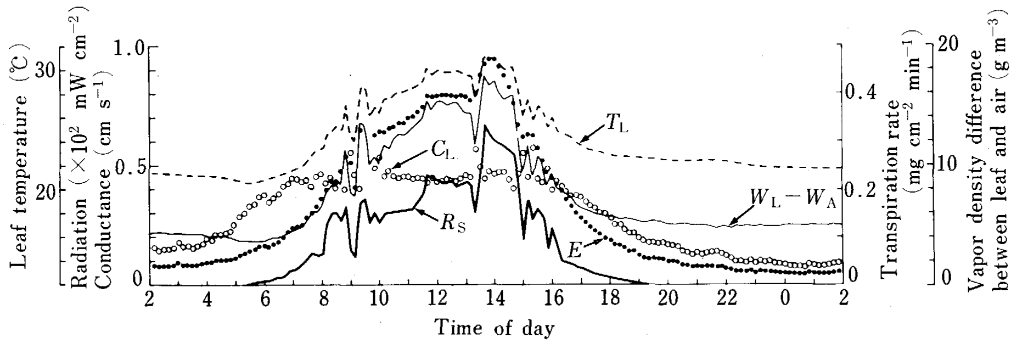

Fig. 1. Diurnal variations of transpiration rate (E), leaf conductance (C_L), leaf temperature (T_L), vapor density difference ($W_L - W_A$) between leaf and air and short wave radiant flux density (R_S) of solar radiation at air temperature of 23°C and relative humidity of 70% in the phytotron glass room on a fair day.

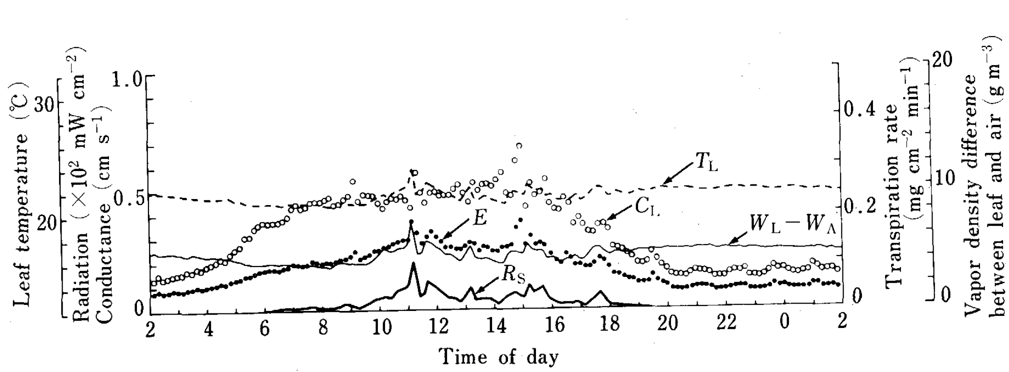

Fig. 2. Diurnal variations of transpiration rate (E), leaf conductance (C_L), leaf temperature (T_L), vapor density difference ($W_L - W_A$) between leaf and air and short wave radiant flux density (R_S) of solar radiation at air temperature of 23°C and relative humidity of 70% in the phytotron glass room on a rainy day.

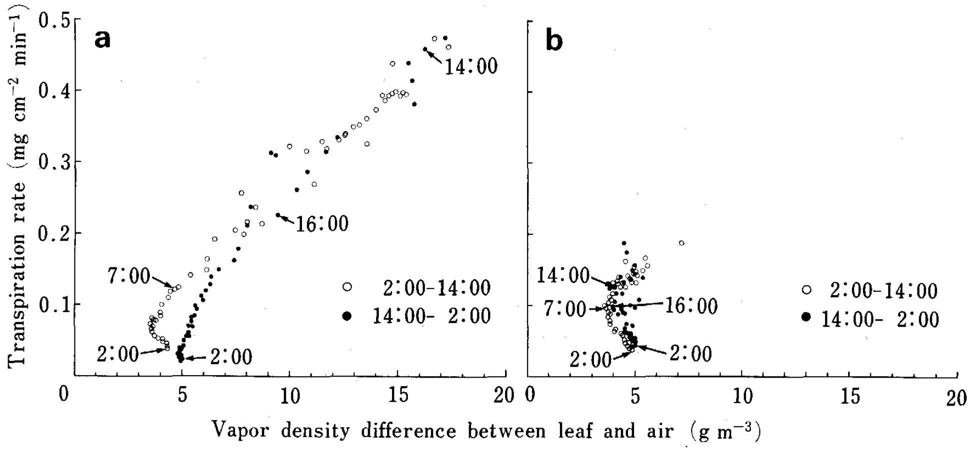

Fig. 3. Respective distributions of transpiration rate (E) on vapor density difference ($W_L - W_A$) between leaf and air in a phytotron glass room on a fair day (a) and a rainy day (b).

Figure 3 shows respective distributions of E on $W_L - W_A$ on the fair day (a) and the rainy day (b). As expressed by Eq. (2), the ratio of E to $W_L - W_A$ at each plot corresponded to each C_L. In the daytime (7:00—16:00) on both of the fair day and the rainy day, most of the data distributed around a straight line passing the origin (0) of the coordinates. That is, the relation between E and $W_L - W_A$ appeared almost linear. From the fact that the ratios of E to $W_L - W_A$ changed at the times around sunrise and sunset when $W_L - W_A$ was almost constant, it could be estimated that stomatal movement is responsible for E at those times.

Thus, stomatal aperture in the cucumber leaf increased even under lower light intensities, but C_L was kept almost constant in the daytime without the influence of solar radiation. On the other hand, E in the daytime linearly related to $W_L - W_A$ which varied with T_L affected directly by solar radiation. This fact suggests that the evaporative demand against the plant varies with the intensities of solar radiation.

Artificial light growth chamber

E, C_L, T_L and $W_L - W_A$ were examined under the artificial light at PPFD of 45 nE cm^{-2} s^{-1} in photoperiod of 12 h (8:00–20:00), air temperature of 23°C and relative humidity of 70% in the growth chamber. Metal halide lamps (Yoko lamp, DR400, TOSHIBA CORPORATION) were used as the light source. This light source is widely used in growth chambers as its spectral distribution is suitable for plant growth. However, there is strong infrared radiation (thermal radiation) which raises the temperature of plants. This infrared radiation can be removed selectively by using a heat absorbing filter attached in front of each lamp. Figure 4 shows spectral transmittance of the heat absorbing (HA) filter (HG, Ohara Optical Glass Mfg. Co., Ltd.) used and spectral energy distributions of the metal halide (MH) lamps. By attaching the HA filter, most of the infrared radiation was removed, and PPFD was decreased to about 85%. So, light intensity in visible region was set at equal PPFD in the respective lights by adjusting the distance between the plant and the lamps.

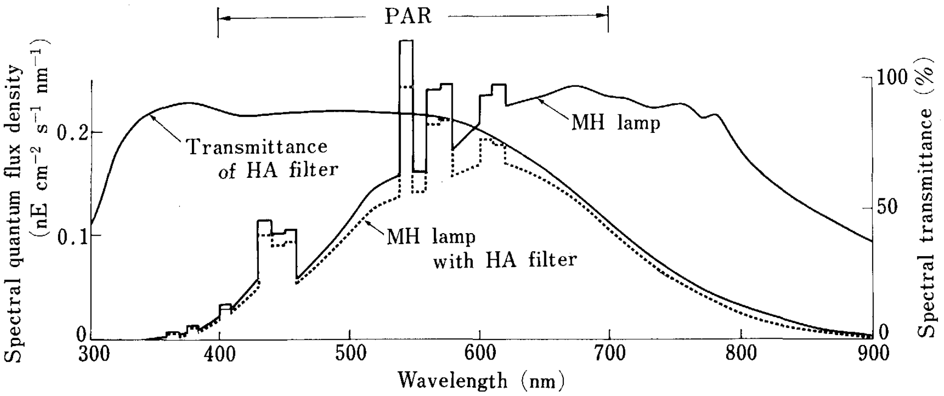

Fig. 4. Spectral transmittance of heat absorbing (HA) filter and spectral energy distributions of metal halide (MH) lamps.

Figures 5 and 6 show diurnal variations of E, C_L, T_L, $W_L - W_A$ and R_S under the respective light conditions of MH lamps with HA filter and MH lamps without HA filter. By attaching HA filter (Fig. 5), R_S was decreased to approximately half, and the rises in T_L and $W_L - W_A$ by lighting were also decreased to approximately half of those under MH lamps without HA filter. E and C_L started to increase gradually at 4: 00 even in dark period and rapidly rose at the time of lighting (8: 00) under both of the two light conditions. The elevation of E under MH lamps without HA filter was about 1.5-fold higher than that under MH lamps with HA filter. On the other hand, the elevations of C_L were almost the same (about 0.4 cm s^{-1}) under the both light conditions. This indicates that the infrared radiation strongly affects E but is not so responsible for C_L.

Figure 7 shows the distribution of E on $W_L - W_A$ under both of the light conditions of MH lamps with HA filter and MH lamps without HA filter. Under both of the light conditions, most of the data in light period distributed around a straight line passing the origin (0), and increase in E was approximately proportional

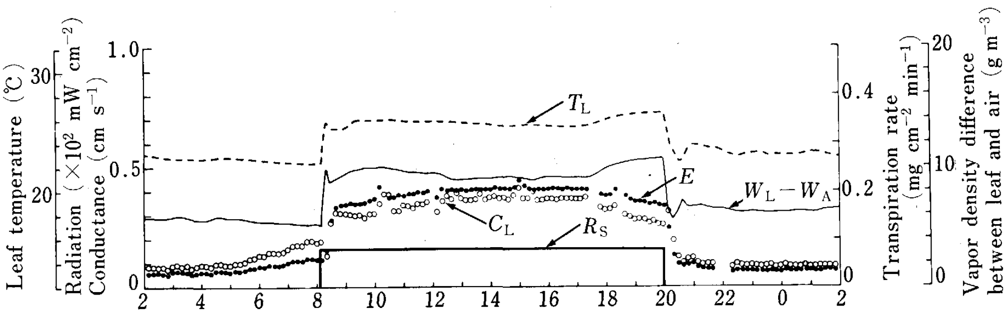

Fig. 5. Diurnal variations of transpiration rate (E), leaf conductance (C_L), leaf temperature (T_L), vapor density difference ($W_L - W_A$) between leaf and air and short wave radiant flux density (R_S) under the light of metal halide lamps with heat absorbing filter at PPFD of 45 nE cm^{-2} s^{-1} in photoperiod of 12 h (8: 00–20: 00), air temperature of 23°C and relative humidity of 70% in the growth chamber.

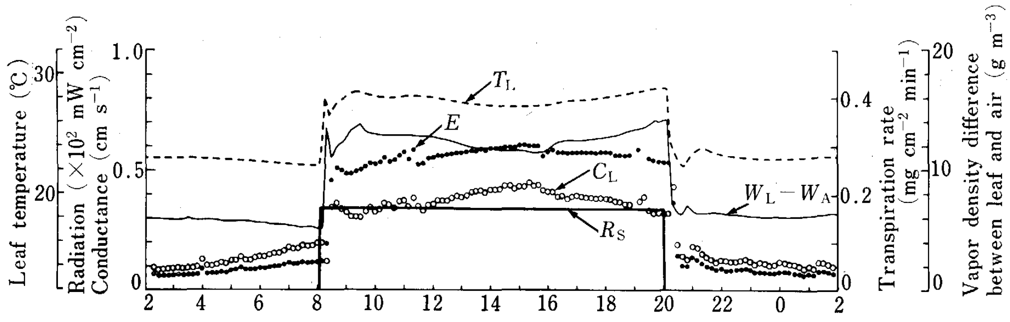

Fig. 6. Diurnal variations of transpiration rate (E), leaf conductance (C_L), leaf temperature (T_L), vapor density difference (W_L-W_A) between leaf and air and short wave radiant flux density (R_S) under the light of metal halide lamps without heat absorbing filter at PPFD of 45 nE cm^{-2} s^{-1} in photoperiod of 12 hr (8: 00–20: 00), air temperature of 23°C and relative humidity of 70% in the growth chamber.

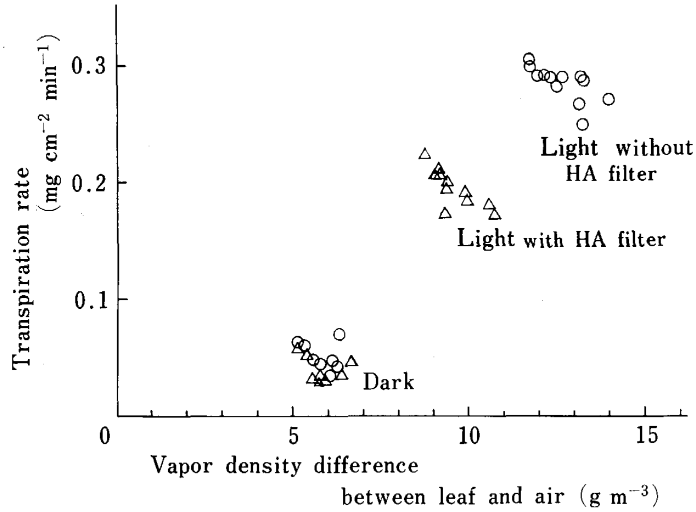

Fig. 7. Distribution of transpiration rate (E) on vapor density difference (W_L-W_A) between leaf and air under both of the lights of metal halide lamps with heat absorbing filter (△) and metal halide lamps without heat absorbing filter (○).

to increase in W_L-W_A: E and W_L-W_A under MH lamps without HA filter was about 1.5-fold higher than those under MH lamps with HA filter. Thus, increase in T_L by infrared radiation caused the increase in W_L-W_A responsible for the evaporative demand against the plant, and E under MH lamps without HA filter was remarkably increased even when C_L was almost equal under both of the light conditions without influences of the infrared radiation. In long term experiments, HA filter was effective for healthy growth under the MH lamps used: The leaf color appeared pale at the edge in the case that HA filters were removed from MH lamps.

In general, many kinds of artificial light sources are used in the growth chambers, and there are distinct differences in spectral composition among the artificial lights. So, the light condition could not be specified for the plant growth, even if the intensity of the artificial light is kept equal in visible light region (PAR). Tibbitts *et al.* (*21*) reported clear differences in plant growth under different artificial lights at equal PPFD. Matsui *et al.* (*16*) examined spectral dependence of leaf conductance and transpiration rate in visible light region. Furthermore, the influences of infrared radiation on plant growth have been analyzed under various light conditions (*6*, *13*, *15*, *17*, *18*). It is known that the plant responds to spectral energy distribution in visible light region through various physiological processes (*2*, *3*, *5*, *10*, *12*, *20*, *22*, *23*). On the other hand, it could be conceivable from the results of this experiment that infrared radiation influences transpiration mainly through the physical process by temperature effect increasing evaporative demand against the plant, and the infrared radiation could be considered as one of the factors causing differences in plant growth under different artificial lights. From these viewpoints, it could be estimated that the artificial light should be identified for plant researches in wider wavelength regions containing infrared.

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