CONTROL OF EVAPORATIVE DEMAND ON TRANSPIRING PLANTS III. TRANSPIRATION AND GROWTH OF CUCUMBER UNDER CONTROLLED EVAPORATIVE DEMAND

Kitano, Masaharu
Biotron Institute Kyushu University

Hamakoga, Michio
Biotron Institute Kyushu University

Eguchi, Hiromi
Biotron Institute Kyushu University

出版情報：BIOTRONICS. 23, pp.105-111, 1994-12. Biotron Institute, Kyushu University

BIOTRONICS **23**, 105–111, 1994

CONTROL OF EVAPORATIVE DEMAND ON TRANSPIRING PLANTS III. TRANSPIRATION AND GROWTH OF CUCUMBER UNDER CONTROLLED EVAPORATIVE DEMAND

M. KITANO, M. HAMAKOGA and H. EGUCHI

Biotron Institute, Kyushu University 12, Fukuoka 812, Japan

(Received August 22, 1994; accepted September 9, 1994)

KITANO M., HAMAKOGA M. and EGUCHI H. *Control of evaporative demand on transpiring plants III. Transpiration and growth of cucumber under controlled evaporative demand.* BIOTRONICS **23**, 105–111, 1994. The Control of evaporative demand on transpiring plants was performed in natural light growth chambers, and transpiration, stomatal conductance and dry matter production of cucumber seedling (*Cucumis sativus* L.) were analyzed under different conditions of the controlled evaporative demand. Under the lower evaporative demand, transpiration was extremely depressed, and stomatal conductance and turgor-driven leaf expansion were enhanced. These effects of the lower evaporative demand brought the higher photosynthetic dry matter production with the higher water use efficiency. From the results, it is suggested that the control of evaporative demand can be a reliable measure to manipulate water use and dry matter production of plants.

Key words: *Cucumis sativus* L.; water relations; evaporative demand; transpiration; dry matter production.

INTRODUCTION

Evaporative demand on transpiring plants directly affects plant water relations through dynamics such as water balance, stomatal movement and leaf expansion (*7, 9, 11, 12*). Evaporative demand largely depends on air humidity as well as irradiance (*8*), and effects of evaporative demand on horticultural crops have been studied with special reference to humidity effects on yield, quality and nutrients accumulation (e. g. *1–6, 13*). In the preceding paper (*10*), the control of evaporative demand was performed in a growth chamber by adjusting air humidity according to variation in solar irradiance.

The present paper deals with effects of the controlled evaporative demand on water use, stomatal conductance and dry matter production in cucumber plants.

MATERIAL AND METHODS

Control of evaporative demand

Evaporative demand (ED_A) on unit area of an amphistomatous leaf can be evaluated on-line by using physical environmental factors of short wave irradiance, air temperature, humidity and wind velocity as follows (*7*, *8*)

$$ED_A = \frac{2C_P\rho G_E(1-RH/100)SAV + \Delta\{\alpha R_S - 2\sigma\varepsilon_L(1-\varepsilon_A)T_A^4\}}{(\gamma G_E/G_{AV}+\Delta)\lambda}$$

with

$$G_E = G_{AH} + 4\sigma\varepsilon_L T_E^3/C_P\rho$$

where G_{AH} and G_{AV} are the leaf boundary layer conductances for the respective transferrs of heat and water vapor, $C_P\rho$ the volumetric heat capacity of air, RH the relative humidity of air, SAV the saturation water vapor density of air, Δ the slope of the saturation vapor density curve, R_S the short wave radiant flux density, α the short wave absorption coefficient of a leaf, σ the Stefan-Boltzmann constant, ε_L and ε_A the respective emissivities of a leaf and the environment, T_A the air temperature, T_E the equivalent temperature between a leaf and the environment, λ the latent heat of vaporization of water and γ the thermodynamic psychrometer constant ($\gamma = C_P\rho/\lambda$).

ED_A is highly sensitive to respective changes in R_S and RH (*8*), and the reliable control of ED_A was perfomed in a natural light growth chamber, where RH was adjusted to diurnal variation in solar R_S by using the sensitivity ($\partial ED_A/\partial RH$) of ED_A to change in RH as follows (*10*)

$$\Delta RH = (SED_A - ED_A)/(\partial ED_A/\partial RH)$$

where ΔRH is the RH deviation to be adjusted and SED_A the desired value of ED_A. Thus, by applying the on-line system for ED_A evaluation and RH adjustment in a growth chamber, ED_A was able to be controlled at a desired value even under R_S variation.

Plant material and experimental procedures

Cucumber plants (*Cucumis sativus* L. cv. Chojitsu-Ochiai) were potted in vermiculite moistened with nutrient solution and grown at T_A of 23℃ and RH of 70% in a phytotron glass room. The seedlings of healthy growth at the 1st leaf stage were transferred to three adjacent growth chambers and grown under the same natural light condition. In the respective growth chambers, ED_A was controlled at different conditions (high, medium and low ED_A) under diurnal variation in solar R_S by adjusting RH as mentioned above, where SED_A was set at each value of 140, 80 and 20 mg/m²/s at T_A of 23℃.

Transpiration rate per unit leaf area (E_A) was evaluated by dividing transpiration rate per plant (E) by the total leaf area ($LA = \Sigma LA_i$): E was measured on-line by weighing the plant and pot, and each leaf area (LA_i) was evaluated from the midrib length (LL_i) on the basis of a LA_i-LL_i relationship obtained as $LA_i = 1.265\,LL_i^2 - 4.784\,LL_i + 12.79$, where LL_i of each leaf was measured by a rule at every 9:00 a.m. Stomatal conductance (G_S) was evaluated form E_A and leaf temperature (T_L) measured by fine thermocouples inserted into leaves (*7, 9*). After the 10 days cultivations under the respective ED_A conditions, dry weight of leaves (DW(L)), dry weight of stems with petioles (DW(S)) and shoot length (SL) were measured, and water use efficiency (WUE) was evaluated by $\{DW(\mathrm{L})+DW(\mathrm{S})\}/\Sigma E$, where ΣE was the integrated E during the 10 days cultivation.

RESULTS AND DISCUSSION

In the respective three growth chambers with SED_A of 140, 80 and 20 mg/m²/s, RH, ED_A, E_A, G_S and T_L appeared in different diurnal variations. Figures 1 and 2 show diurnal variations of R_S, RH, ED_A, E_A, G_S and T_L on successive cloudy day (Feb. 2, 1993) and fair day (Feb. 3, 1993). In two growth chambers with the higher SED_A of 140 and 80 mg/m²/s (i.e. lower humidity conditions), RH was adjusted to 45% and 75% at the fair midday respectively, and ED_A was kept constant at each SED_A of 140 and 80 mg/m²/s independent of R_S variation. In the growth chamber with the lowest SED_A of 20 mg/m²/s (i.e. the highest humidity condition), RH was adjusted from 80% (night) to 95% (fair midday), and ED_A was controlled at SED_A of 20 mg/m²/s under lower R_S condition, while ED_A increased to 50 mg/m²/s around the fair midday by the excessively high R_S.

E_A varied diurnally with R_S and G_S even under the constant conditions of ED_A, but the level of E_A variation became higher in the higher ED_A chambers (Fig. 2). On the other hand, G_S appeared higher in the lower ED_A chambers. In particular, G_S under the lower R_S conditions (e.g. the early morning, cloudy midday and late afternoon) was remarkably high in the lowest ED_A chamber as

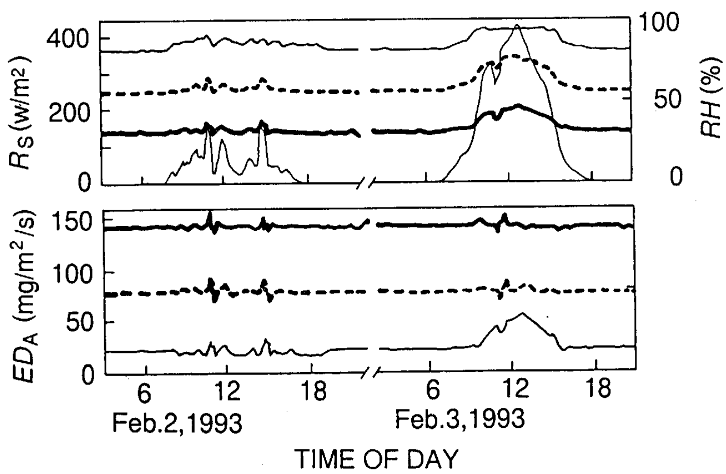

Fig. 1. Diurnal variations of short wave solar irradiance (R_S), relative humidity (RH) and evaporative demand (ED_A) on a cloudy day (Feb. 2, 1993) and a fair day (Feb. 3, 1993) in three growth chambers lit with the natural light, where ED_A was controlled at around the respective desired values of 140 (——), 80 (- - -) and 20 (——) mg/m²/s by adjusting RH according to variation in R_S at an air temperature of 23℃.

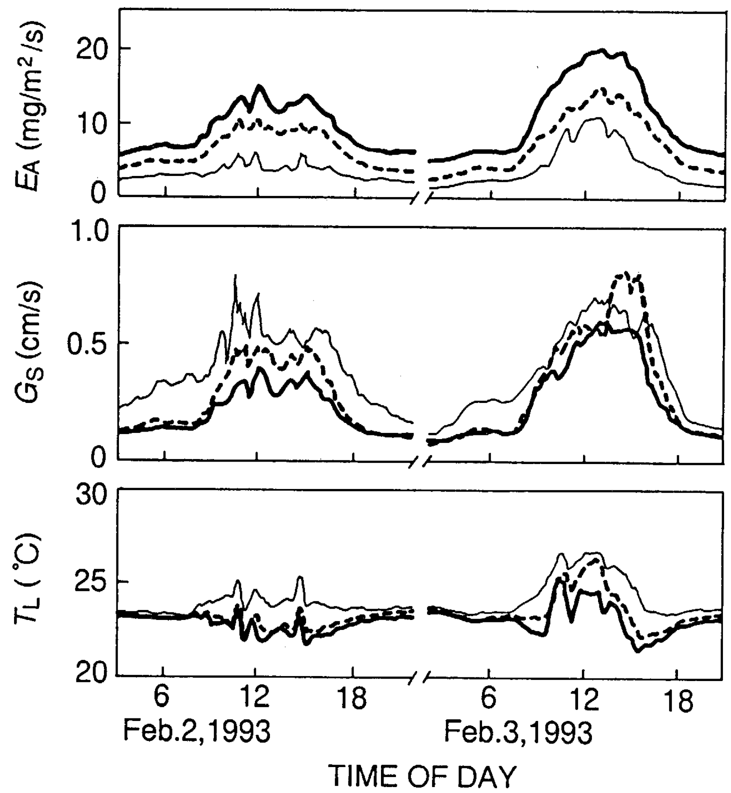

Fig. 2. Diurnal variations of transpiration rate (E_A), stomatal conductance (G_S) and leaf temperature (T_L) on a cloudy day (Feb. 2, 1993) and a fair day (Feb. 3, 1993) in three growth chambers lit with the natural light, where ED_A was controlled at around the respective desired values of 140 (——), 80 (- - -) and 20 (——) mg/m²/s at an air temperature of 23℃ as shown in Fig. 1.

compared with that in the higher ED_A chambers. T_L appeared higher in the lower ED_A chambers because of the lower evaporative cooling brought with the lower E_A. The mean values of E_A, G_S and T_L during the 10 days cultivations under the respective ED_A conditions were calculated by separating the daytime (6:00—18:00) and nighttime (18:00—6:00) values (Table 1). The mean E_A under the lowest ED_A (20 mg/m²/s) was 60 to 70% lower than that under the highest ED_A (140 mg/m²/s), whereas the mean G_S became 56 to 79% higher under the lowest ED_A as compared with the highest ED_A. Difference found in the mean T_L was not more than 1.3℃.

Growth indices (DW(L), DW(S), DW(L+S), LA, DW(L)/LA and SL) and WUE after the 10 days cultivations under the different ED_A conditions were listed in Table 2. The larger dry weights were obtained under the lower ED_A conditions, and the dry weights were about 40% larger in the lowest ED_A than in the highest ED_A. Furthermore, LA was much more increased in the lower ED_A conditions, and LA under the lowest ED_A became 63% larger than that in the highest ED_A. This larger increase in LA resulted in the lower dry weight per unit leaf area (DW(L)/LA), and DW(L)/LA under the lowest ED_A became 87%

Table 1. Transpiration rate per unit leaf area (E_A), stomatal conductance (G_S) and leaf temperature (T_L) in the daytime (D) from 6:00 to 18:00 and in the nighttime (N) from 18:00 to 6:00 under the different conditions of evaporative demand (ED_A) of 140, 80 and 20 mg/m²/s at an air temperature of 23℃. The values of E_A, G_S and T_L are the mean values for 10 successive days, and each value in the parenthesis is the relative percentage compared with the value under ED_A of 140 mg/m²/s.

ED_A (mg/m²/s)	E_A (mg/m²/s) D	E_A (mg/m²/s) N	G_S (cm/s) D	G_S (cm/s) N	T_L (℃) D	T_L (℃) N
140 (100)	14.20 (100)	7.72 (100)	0.35 (100)	0.13 (100)	23.2	23.4
80 (57)	10.00 (70)	4.56 (59)	0.42 (121)	0.14 (109)	23.6	23.4
20 (14)	5.72 (40)	2.34 (30)	0.55 (156)	0.23 (179)	24.5	23.8

Table 2. Dry weights (DW) of leaves (L) and stems (S), leaf area (LA), dry weight per unit leaf area (DW (L)/LA), shoot length (SL) and water use efficiency (WUE) after the 10 days cultvations under different conditions of evaporative demand (ED_A) of 140, 80 and 20 mg/m²/s at an air temperature of 23℃. Each value in the parenthesis is the relative percentage compared with the value under ED_A of 140 mg/m²/s.

ED_A (mg/m²/s)	DW (L) (g)	DW (S) (g)	DW (L+S) (g)	LA (m²)	DW (L)/LA (g/m²)	SL (cm)	WUE (mg/g)
140	2.66 (100)	0.86 (100)	3.52 (100)	0.856 (100)	3.11 (100)	47.7 (100)	1.87 (100)
80	3.34 (125)	1.04 (121)	4.38 (124)	1.114 (130)	3.00 (96)	53.4 (112)	2.88 (154)
20	3.79 (142)	1.21 (141)	5.00 (142)	1.391 (163)	2.73 (87)	55.0 (115)	5.03 (269)

of that under the highest ED_A. A slight difference was also found in SL, and SL under the lowest ED_A was 15% larger than that in the highest ED_A. WUE under the lowest ED_A became more than 2.5 times higher than that under the highest ED_A.

Effects of the low ED_A condition (high humidity) on the growth indices were further studied under the different conditions of daytime (D)/nighttime (N) ED_A, where the seedlings were grown for 10 days under the respective D/N ED_A conditions of 140/140, 140/20 and 20/140 mg/m²/s (Table 3). DW's and LA under D/N ED_A conditions of 140/20 and 20/140 mg/m²/s became larger than those under 140/140 ED_A condition, and those increases in DW's and LA appeared more clearly under D/N ED_A of 20/140 mg/m²/s as compared with under D/N ED_A of 140/20 mg/m²/s. That is, the daytime low ED_A brought larger effects than the nighttime low ED_A.

Transpiration extremely increased with evaporative demand from the environment, but a proportional relationship was not found between them

Table 3. Dry weights (*DW*) of leaves (L) and stems (S), leaf area (*LA*), dry weight per unit leaf area (*DW*(L)/*LA*) and shoot length (*SL*) after the 10 days cultvations under different daytime/nighttime conditions of evaporative demand (ED_A) of 140/140, 140/20 and 20/140 mg/m²/s at an air temperature of 23℃. Each value in the parenthesis is the relative percentage compared with the value under daytime/nighttime ED_A of 140/140 mg/m²/s. D, daytime from 6:00 to 18:00; N, nighttime from 18:00 to 6:00.

ED_A(mg/m²/s) D	N	*DW* (L) (g)	*DW* (S) (g)	*DW* (L+S) (g)	*LA* (m²)	*DW* (L)/*LA* (g/m²)	*SL* (cm)
140	140	3.16 (100)	1.14 (100)	4.30 (100)	1.059 (100)	2.98 (100)	49.0 (100)
140	20	3.47 (110)	1.34 (118)	4.81 (112)	1.389 (131)	2.50 (84)	57.6 (118)
20	140	4.64 (147)	1.77 (155)	6.41 (149)	1.803 (170)	2.57 (86)	62.5 (128)

because of stomatal response to the evaporative demand (i.e. G_S increase under the lower ED_A conditions). Stomatal aperture and leaf expansion were remarkably enhanced under the lower evaporative demand which brought about higher turgor in guard cells and epidermal cells by depressing water loss from these cells. Effect of evaporative demand on dry matter production can be considered to be brought through change in photosynthetic productivity regulated by stomatal movement and through change in turgor-driven leaf expansion: The effect of the daytime low ED_A relates to both of those changes, whereas the effect of the nighttime low ED_A can be attributed to only the latter change. The larger stomatal conductance and the larger leaf area brought under the lower evaporative demand contribute to the higher dry matter production by photosynthesis, and this higher dry matter production with the depressed water loss resulted in the higher water use efficiency. These effects of evaporative demand suggest that the control of evaporative demand can be a reliable measure for manipulating transpiration and resultantly for optimalizing plant water relations and growth.

REFERENCES

1. Adams P. (1991) Effect of diurnal fluctuations in humidity on the accumulation of nutrients in the leaves of tomato (*Lycopersicon esculentum*). *J. Hort. Sci.* **66**, 545–550.
2. Bakker J. C., Welles G. W. H. and van Uffelen J. A. M. (1987) The effects of day and night humidity on yield and quality of glasshouse cucumbers. *J. Hort. Sci.* **62**, 363–370.
3. Bakker J. C. (1990) Effects of day and night humidity on yield and fruit quality of glasshouse tomatoes (*Lycopersicon esculentum* Mill.). *J. Hort. Sci.* **65**, 323–331.
4. Gislerod H. R., Selmer-Olsen A. R. and Mortensen L. M. (1987) The effect of air humidity on nutrient uptake of some greenhouse plants. *Plant and Soil* **102**, 193–196.
5. Grange R. I. and Hand D. W. (1987) A review of the effects of atmospheric humidity on the growth of horticultural crops. *J. Hort. Sci.* **62**, 125–134.
6. Jolliet O., Bailey B. J., Hand D. J. and Cockshull K. (1993) Tomato yield in greenhouses related to humidity and transpiration. *Acta Hort.* **328**, 115–124.

7. Kitano M. and Eguchi H. (1991) Dynamics of plant water relations as affected by evaporative demand. Pages 367–372 *in* Y. Hashimoto and W. Day (eds) *Mathematical and Control Applications in Agriculture and Horticulture.* Pergamon Press, Oxford.
8. Kitano M., Hamakoga M. and Eguchi H. (1991) Control of evaporative demand on transpiring plants I. Sensitivity of evaporative demand to environmental factors. *Bioronics* **20**, 53–64.
9. Kitano M. and Eguchi H. (1992) Dynamics of whole-plant water balance and leaf growth in response to evaporative demand. I and Ⅱ. *Biotronics* **21**, 39–60.
10. Kitano M., Hamakoga M. and Eguchi H. (1992) Control of evaporative demand on transpiring plants Ⅱ. Control algorithm and performance. *Biotronics* **21**, 61–68.
11. Kitano M. and Eguchi H. (1993) An impact coefficient of evaporative demand on plant water balance. *Biotronics* **22**, 61–72.
12. Kitano M. and Eguchi H. (1993) Dynamic analyses of water relations and leaf growth in cucumber plants under midday water deficit. *Biotoronics* **22**, 73–85.
13. Tibbitts T. W. and Bottenberg G. (1976) Growth of lettuce under controlled humidity levels. *J. Amer. Soc. Hort. Sci.* **101**, 70–73.