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Hirota, Osamu
Institute of Tropical Agriculture, Kyushu University

Villavicencio, Eduardo
Proyecto Agricola JICA/FFM/ESSA Guerrero Neguro, B. C. Sur.

Chikushi, Jiro
Biotron Institute, Kyushu University

Takeuchi, Shinichi
Kyushu Kyouritsu University

他

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Effect of Saline Water Irrigation at Fruit Maturity Stage on Transpiration Rate and Growth in Sweet Pepper (*Capsicum annuum*)

Osamu Hirota*, Eduardo Villavicencio*[1], Jiro Chikushi*[2], Shinichi Takeuchi*[3] and Yoshisuke Nakano*[4]

*Institute of Tropical Agriculture, Kyushu University, Fukuoka 812–8581, Japan
*[1]Proyecto Agricola JICA/FFM/ESSA Guerrero Neguro, B. C. Sur., Mexico
*[2] Biotron Institute, Kyushu University, Fukuoka 812–8581, Japan
*[3] Kyushu Kyouritsu University, Kitakyushu 807–8585, Japan
*[4] Faculty of Agriculture, Kyushu University, Fukuoka 812–8581, Japan
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Pot sand culture of sweet pepper was carried out to ascertain the effect of saline water irrigation on growth. For the plants of fruit maturing stage, we applied saline water of 500 ml per plant every three days at five concentration levels (saline content [or electric conductivity]=0.69% [6.95 $mS \cdot cm^{-1}$], 0.55 [5.68], 0.41 [4.42], 0.28 [3.12], control [0.10]). Growth analyses were carried out after 22 days saline water treatment. Relative growth rate (RGR) was inhibited according to saline content, resulting from retardation of net assimilation rate (NAR), but not from retardation of leaf area ratio (LAR). On the other hand, the leaf expansion rate was inhibited by saline. From these results, therefore, saline did not affect the growth balance between leaf and the other organs. Retardation of NAR was related to obstruction of stomatal conductance and transpiration.

INTRODUCTION

Some kinds of vegetable have been cultivated in arid regions due to the demand of the peoples, who want to take fresh vegetables from neighbors. During the cultivation, crops have been suffered from salinity hazards. To maintain the yield of crops constantly some treatments must be performed for the hazards according to salt tolerance of the plants.

Reduction in crop growth and yield due to salinity has been well documented by Maas and Hoffman (1977), although different physiological processes have been suggested as causes of the reduction in different species. Two reported causes of growth reduction are faulty leaf development and photosynthetic process damage. Carbon assimilation is central to plant growth and productivity, and a better understanding of factors contributing to its inhibition due to excess salinity may provide future strategies for culture improvement (Bethke and Drew, 1992). In short, though sweet pepper has been identified as belonging to a low salinity tolerant plant (Maas and Hoffman, 1977), if various features of its salt inhibition can be clarified, it might be improved in terms of salt tolerance.

In a desert field in Baja California, Mexico, chili has been cropped as a salt tolerance vegetable. Thus, we can consider that the sweet pepper, which species is the same as chili, might be also suitable for the climate condition in the arid land.

This paper focuses on saline effects on sweet pepper growth in terms of growth rate, assimilation rates and transpiration aspects at the maturing stage.

MATERIALS AND METGHODS

General and salinity treatment

The experiment was conducted in a green house located in Kyushu University, Japan, from June to September 1996. Sweet pepper (*Capsicum annuum*, cv. Yayoi,TAKII co.) seeds were uniformly sown in plastic pots (top diameter 9.0, bottom 6.5 and height 7.5 cm), filled with vermiculite, on Jun 15, 1996. The fertilizer OKF1 (N: P_2O_5: K_2O: MgO=15: 8: 17: 2%, Otsuka Co.) was applied by solution (N: P_2O_5: K_2O: MgO=300: 160: 340: 40 ppm). On July 5 the sweet pepper seedlings were transplanted to plastic pots (top diameter 19, bottom 16 and height 21 cm), filled with well washed sand, at one seedling per pot.

Total number of pots used was 100. The nutrient solution of 400 ml was applied at 400 ml per pot once or twice daily depending on weather conditions. Just before the start of saline water irrigation, eighty pots with normally growing plants were selected for the experimental specimen and solid chemical fertilizer of 10 g (N: P_2O_5: K_2O =16: 5: 10%) was applied to each pot. The eighty pots were grouped into five salt treatments characterized by the concentrations of NaCl and $CaCl_2$, as shown in Table 1. Saline water irrigation was initiated on August 26, with the application of 500 ml every three days. Water was supplemented depending on weather conditions except on the day of saline irrigation. Electric conductivity (EC $mS \cdot cm^{-1}$) of irrigation and drainage water were monitored with an electric conduct meter (ECT–200, Shibata Co.). Four plants per treatment were sampled on Aug. 26, Sep. 3, Sep. 10 and Sep. 17. Plants were separated into parts, and fresh fruit was weighed. Each plant part was dried by oven for 48 hours on 80 °C and then weighed. Measurement of transpiration by stem heat balance method and stomatal conductance was carried out.

Measurement of transpiration by Stem heat balance method and stomatal conductance

Whole plant transpiration rate was measured with constant–power sap flow gauge (Sakuratani, 1981, Baker and Van Bavel, 1987), which measured the mass flow rate of water in individual plants. Transpiration rate (T_r) was calculated using the following equation:

$$T_r = \frac{P - K_{st} A[(dT_b + dT_a)/dx] - K_g E}{CdT_{ba}} \quad \cdots\cdots (1)$$

where P is input electric power (W), K_{st} stem thermal conductivity ($W \cdot m^{-1} \cdot K^{-1}$), A stem cross section area (m^2), dT_a/dx and dT_b/dx vertical temperature differences (K) between two points spaced dx above and below the heater, K_g a gauge factor ($W \cdot V^{-1}$) representing radial power loss per volt, through the gauge when T_r=0, E voltage (V) of a thermopile mounted on the outside of the heater encircling the stem, C specific heat capacity ($J \cdot g^{-1} \cdot K^{-1}$) of the xylem sap, and dT_{ba} temperature difference (K) across the heater.

Table 1. Salt concentration and electric conductivity (EC) of irrigation water.

		NaCl	$CaCl_2$	EC
		($mol \cdot m^{-3}$)		($mS \cdot cm^{-1}$)
Treatment	A	127	33	6.95
〃	B	102	26	5.68
〃	C	76	20	4.42
〃	D	51	13	3.12
(control)	E	0	0	0.10

Stem sap flow gauges (model SGA10, Dynamax, Houston, USA) was used for measuring transpiration rate for each treatment. All guages were connected a datalogger–multiplexer unit (model 21X/Am32, Campbell Scientific, Inc.), which can also supply an adjustable voltage (4–5 volt) to the gauge. Before the initiation of saline treatment, five standard grown plants were selected on August 9. These five plants were attached to one gauge and distributed to saline treatment plots A to E (Table 1). During transpiration measurement, sap flow gauges were calibrated by the gravimetric method using an electric balance (METTLER TOLED, sb16001). As available electric balances were limited, treatment A, B and D plots and treatment C and E plots were calibrated separately on September 11 and 16, in fine days, respectively. Data from the balances were recorded every 10 minutes from 7:00 am. Transpiration data obtained by stem gauges was corrected using a regression equation between the data of sap flow gauges and the balances.

For measurement of stomatal conductance, three plants from each treatment were selected. Six leaves from each plant, consisting of two leaves from the top, middle and bottom of each plant, were then selected. Measurement was conducted using a super porometer (Licor–1600) from 10:00 am to 12:00 am on a fine day (Aug. 30).

Measurement of leaf area expansion

In order to estimate leaf expansion during saline treatment, measurement of intact leaf area was necessary. Sweet pepper leaf shape was assumed to be ellipsoid, and could therefore be estimated by measuring the length of the long and short leaf axes. Twenty leaves per pot for each treatment were selected including leaves from top to bottom of the plant and then numbered before saline irrigation. The effectiveness of this method of estimating leaf area without detaching leaves is confirmed in Fig. 1.

Measurement of leaf area using this method was carried out on Aug. 29, Sep. 6 and Sep. 17. The leaf area expansion rates ($LAER$, $cm^2 \cdot cm^{-2}$) were obtained as follow:

$$LAER = \frac{A_2}{A_1} \quad \cdots\cdots (2)$$

where A_1 and A_2 are leaf area ($cm^2 \cdot$ single leaf^{-1}) on Aug. 29 and Sep. 17, respectively.

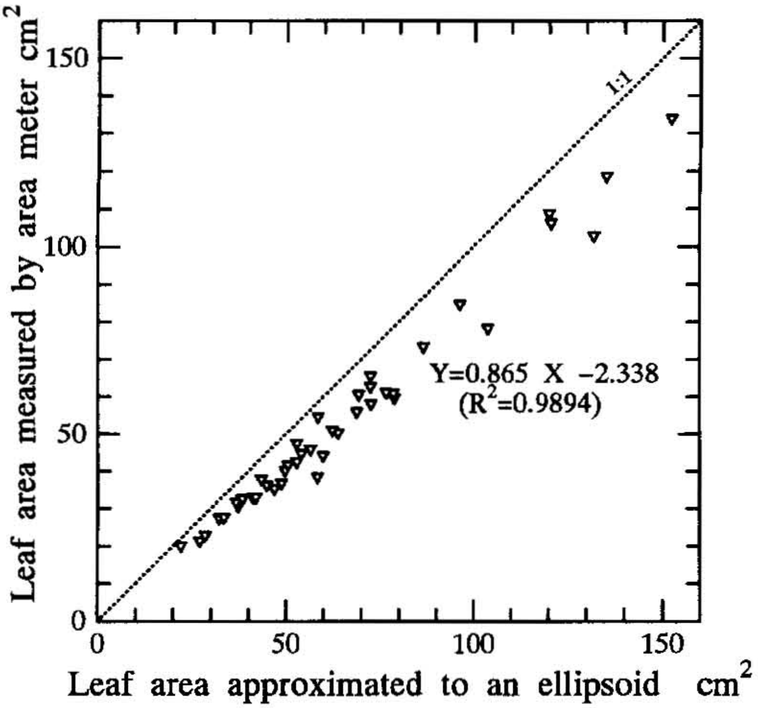

Fig. 1. Relationship between leaf area approximated to an ellipsoid, which is calculated by assuming maximum leaf length to long axis of ellipsoid and maximum width to short axis, and leaf area measured by area meter in sweet pepper plants

Growth analysis

Effects of saline treatment on growth of sweet pepper were analyzed by growth analysis. Mean relative growth rate (*RGR*, day^{-1}) over time interval from t_1 to t_2, net assimilation rate (*NAR*, $g \cdot m^{-2} \cdot day^{-1}$) and leaf area ratio (*LAR*, $m^2 \cdot g^{-1}$) were obtained using the following equations:

$$RGR = \frac{LnW_2 - LnW_1}{t_2 - t_1} \quad \cdots\cdots (3)$$

$$NAR = \frac{(W_2 - W_1)(LnA_2 - LnA_1)}{(t_2 - t_1)(A_2 - A_1)} \quad \cdots\cdots (4)$$

$$LAR = \frac{(A_2 - A_1)}{(W_2 - W_1)} \bullet \frac{(LnW_2 - LnW_1)}{(LnA_2 - LnA_1)} \quad \cdots\cdots (5)$$

where *W* and *A* are mean plant dry matter weight ($g \cdot plant^{-1}$) and mean plant leaf area ($m^2 \cdot plant^{-1}$), respectively. The subscription numbers 1 and 2 indicate t_1 and t_2, respectively.

RESULTS

Growth, growth analysis and Leaf expansion

Dry matter weight and root weight ratios to the whole plant at commencement and end of saline treatment are shown in Fig. 2. Growth was inhibited by saline irrigation in proportion to saline water EC. Root dry weight ratio to whole plant decreased over time from 0.638 at the beginning of saline treatment to 0.413 in control plot E. Root ratio in saline treatment plots ranged from 0.393 to 0.329, indicating a negative effect of saline on root weight ratio. The fruit fresh weight per plant, shown in Fig. 3, decreased linearly in proportion to EC of irrigation water until EC=5.6. When EC became to 5.6, there is no further decrease in fruit fresh weight. The effect of saline on the expansion of leaf area is shown in Fig. 3. The expansion rate of leaf area of control plot E was greater than 1.2. However leaf expansion in saline treated plots was so inhibited in proportion to saline content that its rate decreased to 1.05 at high saline content levels.

Growth analysis results are shown in Fig. 4. RGR and NAR decreased linearly in proportion to saline content, but LAR was not effected.

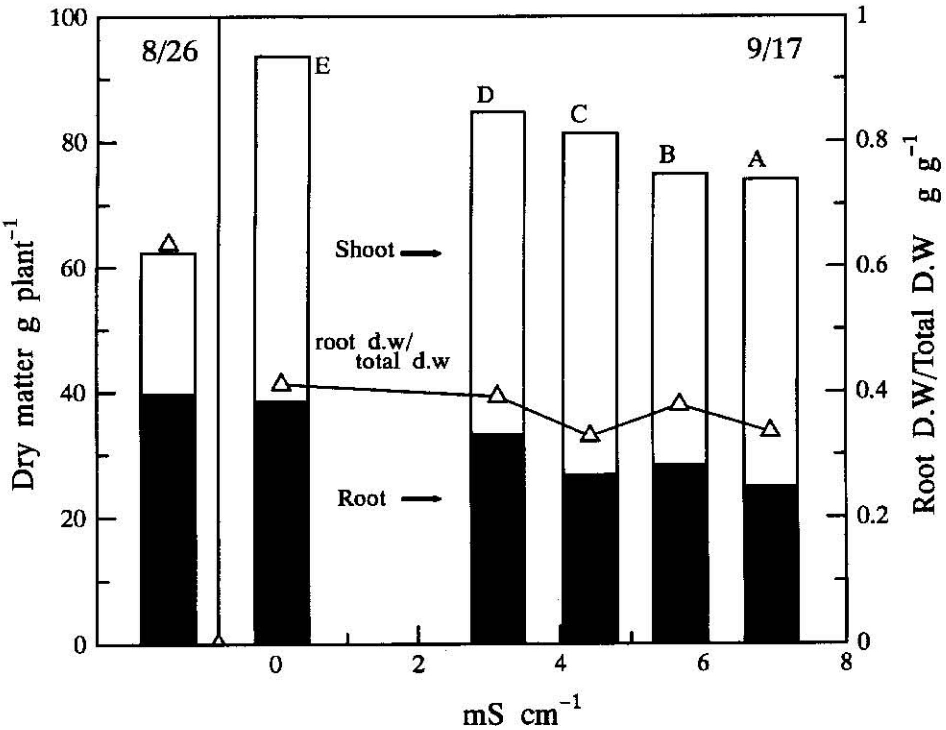

Fig. 2. Total dry matter and root dry weight ratios to total dry weight at different saline water content on Aug. 26 and Sep. 17. Letters A to E are same as treatments A to E in Table 1.

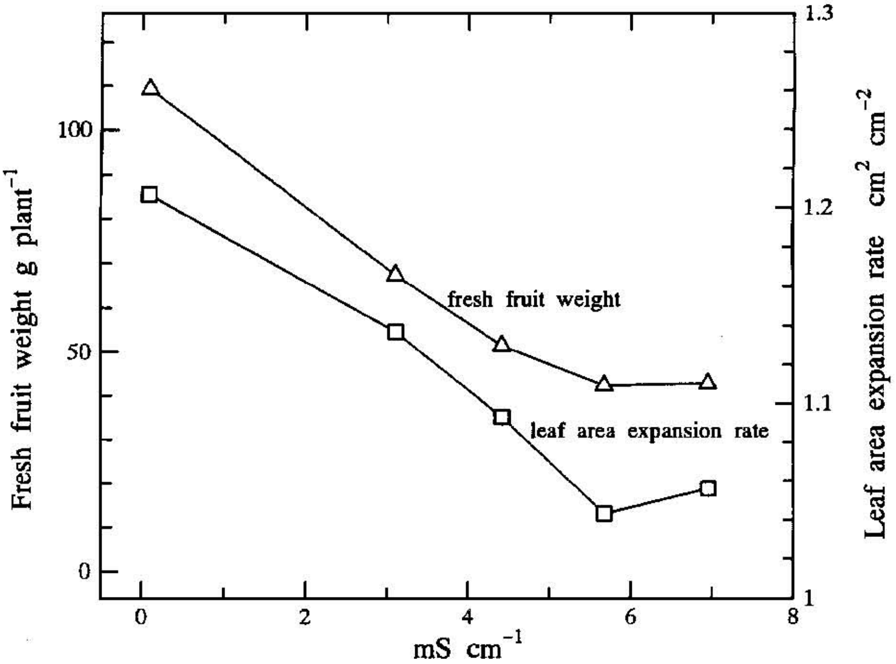

Fig. 3. Effect of saline water content on fresh fruit weight and leaf area expansion rate (LAER) in sweet pepper plants

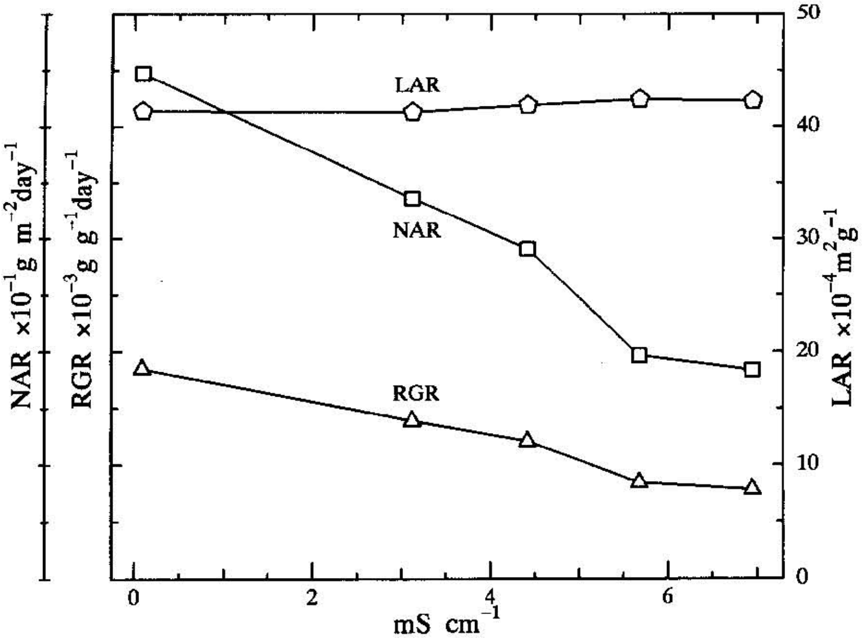

Fig. 4. Relationship between different saline water content and RGR, NAR and LAR

Transpiration rate and stomatal conductance

The relationship between transpiration measured by sap flow gauge and by gravitational method is shown in Fig. 5. Transpiration in treatments A, B and D (Fig. 5–a) show good coincidence for both methods, but transpiration in treatments C and E (Fig. 5–b) are overestimated in comparison with results from the gravitational method. Therefore transpiration data for treatments C and E, measured by sap flow gauge, were corrected using the regression equations. Diurnal change in transpiration rate on

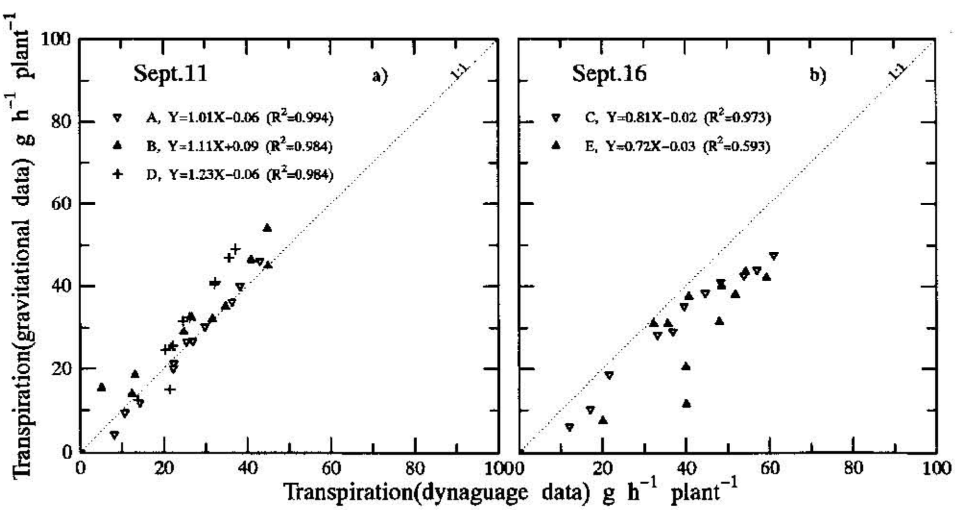

Fig. 5. Comparison between transpiration rates in sweet pepper measured by Dynaguage and gravimetric methods. Letters A to E are same as treatments A to E in Table 1.

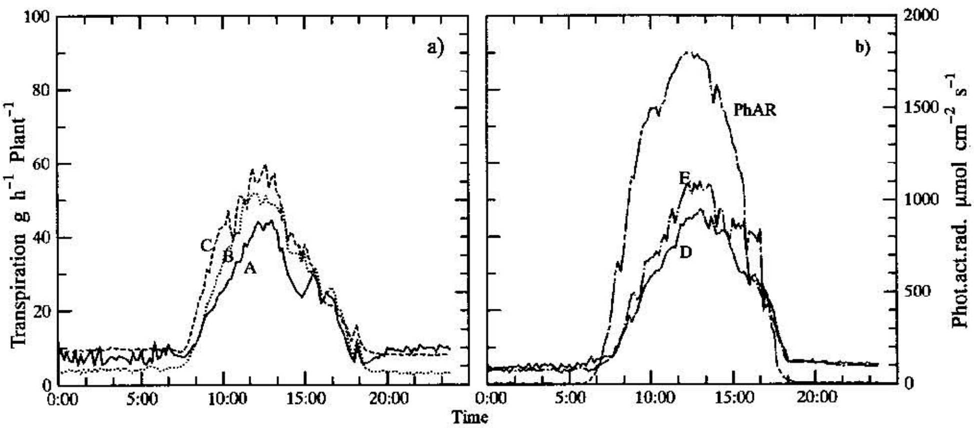

Fig. 6. Diurnal change in transpiration rate in sweet pepper under different saline conditions measured by Dynaguage method (September 11). Letters A to E are same as treatments A to E in Table 1.

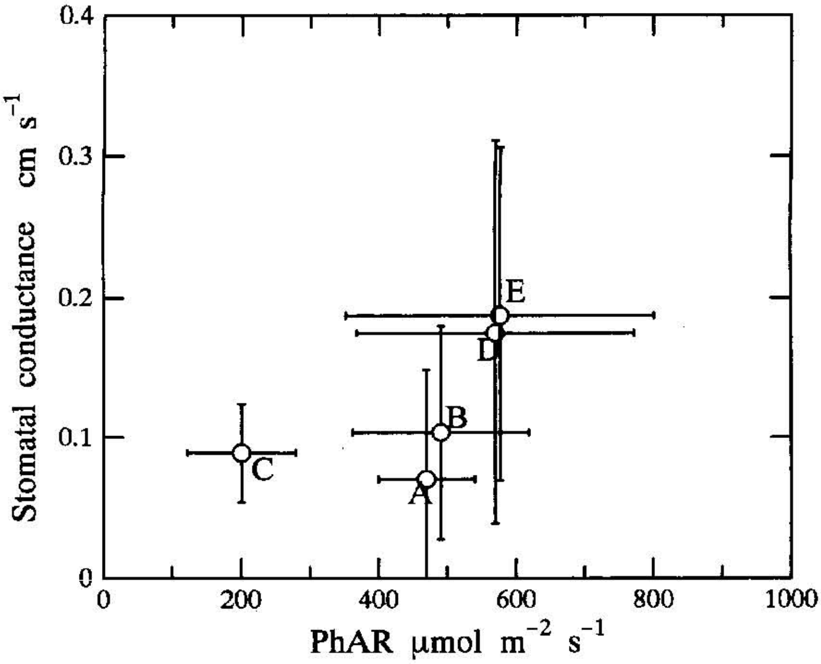

Fig. 7. Stomatal conductance in sweet pepper leaves under different saline conditions (August 27). Bars denote SD. Letters A to E are same as treatments A to E in Table 1.

September 11 is shown in Fig. 6. Transpiration followed light intensity change, but time of the peak transpiration rate was delayed than that of the light intensity. Transpiration rate was inhibited by saline content except treatment C. The relationship between light intensity and stomatal conductance is shown in Fig. 7. Though a large variation in stomatal conductance due to both variation in leaf age and light intensity was observed, a correlation between saline treatment and stomatal conductance, where the higher the saline treatment the lower the stomatal conductance of leaf, was observed except in treatment C. In treatment C the stomatal conductance deviated from the above relation, because average light intensity was far lower than in other treatments.

DISCUSSION

According to the report (Maas and Hoffman 1977) summarizing the saline effect on crop growth, pepper plant (*Capsicum annuum*) is classified to a "moderately sensitive" plant. In the present experiment, sweet pepper growth, both top and root, was inhibited in proportion to saline content and fresh fruit yield was also similarly inhibited. On the other hand, some salinity tolerant plants were reported as follows. Yields of semi-dwarf and durum wheat (Francois *et al.*,1986) did not decline until EC reached 5–6 mS · cm^{-1}. Further sunflower (Francois, 1996) hybrid yield did not decline until EC reached 6 mS · cm^{-1}. Though it is not completely clear as to why the pepper plant is so easily inhibited by saline, the reports (Hoffman *et al.*, 1980, Munns *et al.*, 1982) on growth inhibition of this plant due to saline indicate that the cause is water deficit in young leaves even under lower saline condition and not to adverse effects of ions on metabolism. Shalhevet and Hsiao (1986) stated that turgor pressure in the pepper plant decreased easily even with a slight decline in soil water content. The results of the present experiment, which indicate decline both in stomatal conductance and transpiration rate even at low saline content (Fig. 6, 7), tend to agree with above findings.

In the present experiment, it was demonstrated through growth analysis that growth inhibition, *i.e.* RGR retardation, was induced through reducing NAR by increasing salinity. While both RGR and NAR decreased similarly with saline content, LAR increased slightly rather than decreased (Fig. 4). This indicates RGR decreased due to NAR retardation by saline as indicated above. Similar result has been reported for barley by Cramer *et al.* (1990). In the present experiment, expansion of leaf area was inhibited by saline (Fig. 3) but LAR increased slightly. These indicate that leaf area expansion is not inhibited compared with the inhibition of other organs especially root growth, as indicated by the decline of root weight ratio in higher saline content plots (Fig. 2).

While some crop yields (Bernstein and Francois, 1973, Francois *et al.*, 1986) are not affected by low saline content solution, current pepper experiment shows linear yield reduction due to saline contents. There is, however, no critical saline content within the range of this experiment, in which the yield is damaged completely. From these results we can conclude the saline water cultivation of the sweet pepper plant is useful if the cost balance between input and output of the resources for this cultivation is reasonable.

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