

Effects of Salinity on Growth, Water Relations and Photosynthetic Rate of Tomatoes Grown in Nutrient Film Technique

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ABSTRAK

Tomato (Lycopersicon esculentum Mill. var Counter) ditanam didalam berbagai rawatan saliniti menggunakan teknik nutrien cetek. Dalam kajian pertama, tanaman didedahkan kepada saliniti 2.5, 5.5 dan 8.5 mS cm⁻¹. Pada kajian kedua, tanaman didedahkan kepada saliniti 2.5 dan 8.5 mS cm⁻¹ dan saliniti yang diubah dari tinggi kepada rendah dan sebaliknya. Jisim kering daun dan batang didapati mengurang apabila tanaman didedahkan kepada saliniti 8.5 mS cm⁻¹ yang berterusan. Pendedahan tanaman kepada saliniti tinggi pada peringkat akhir pertumbuhan menghasilkan pengurangan jisim kering daun yang sama dengan tanaman yang didedahkan kepada saliniti yang berterusan. Ini telah dihasilkan oleh kerintangan dalam pergerakan air didalam pokok seperti yang di tunjukkan oleh pengurangan pengambilan air dan potensi air daun. Kadar fotosintesis didapati tidak dipengaruhi walaupun konduksi stomata dan potensi air daun dikurangkan apabila tanaman didedahkan kepada saliniti tinggi.

ABSTRACT

Tomato (Lycopersicon esculentum Mill. var Counter) plants were grown under different salinity conditions using the Nutrient Film Technique (NFT). In the first experiment, plants were exposed to salinities of 2.5, 5.5 and 8.5 mS cm⁻¹. In the second experiment, plants were exposed to continuous salinity of 2.5 and 8.5 mS cm⁻¹ and altered salinity i.e low to high or vice versa. Leaf and stem dry weight were markedly reduced when plants were exposed to continuous salinity of 8.5 mS cm⁻¹. Exposure to high salinity at the later stages of growth also resulted in the reduction of leaf dry weight to a level similar to that of plants exposed to continuous high salinity. This could be attributed to the restriction in the movement of water within the plants as indicated by the reduction in plant water uptake and leaf water potential. Photosynthetic rate was not affected although stomatal conductance and leaf water potential were reduced when plants were exposed to high salinity.

INTRODUCTION

The adverse effects of salinity on tomato growth and fruit production have been extensively studied (Mizrahi and Pasternak 1985; Ehret and Ho 1986; Taleisnik 1987). Plant responses to salinity depend on the stages of plant growth (Maas and Hoffman 1977). High levels of salinity during the seedling stage permanently impaired plant growth (Dumbroff and Cooper 1974; El

Shourbagy and Ahmed 1975). Under hydroponics, the salinity of the nutrient solution can be manipulated to achieve several objectives. High salinity obtained by adding sodium chloride to the nutrient solution was used to shift the plant from vegetative to reproductive development particularly in situation where environmental conditions (e.g. high humidity and low radiation) favour excessive vegetative growth. High salinity

was also reported to be beneficial in improving fruit quality in tomatoes (Hobson and Adams 1988).

Exposure of plants to high salinity normally reduces their growth rate. O'Leary (1969) suggested that a high concentration of salts reduces the hydraulic permeability of the roots, thus restricting the movement of water through the root system. Milford *et al.* (1977) reported that the addition of Na⁺ ion to the root zone stimulates leaf expansion relative to that in the control. However, no evidence was provided to suggest that Na⁺ alters the intrinsic relationships between leaf water potential, relative water content and stomatal conductance. Water uptake by plants grown at high salinity can be equal to that in non saline media; and salinity did not reduce plant turgor within certain limits (Ehlig *et al.* 1968).

Previous studies indicated conflicting results of the effect of high salinity on photosynthesis rate. The reduction in photosynthesis rate of plants subjected to high salinity is related most closely to the stomatal closure of leaves in many plant species e.g. onions, beans and cotton (Gale *et al.* 1967), tomatoes (Lapina and Papov 1970), barley and cotton (Hoffman and Phene 1971), beans (Jensen 1975). However, there were reports indicating that high salinity did not cause a reduction in the leaf photosynthetic rate e.g. tomatoes (Nieman 1962).

The present paper reports the effect of salinity on growth, water relations, stomatal conductance and photosynthetic rate of tomatoes grown in NFT- system. The study also examined the relationships between water relations and photosynthetic rate in plants exposed to high salinity.

MATERIALS AND METHODS

Seven-week old tomato plants (*Lycopersicon esculentum* L. cv Counter) were grown using NFT in the glasshouse at Wye College Kent, England. Mean daily temperature during the period of the experiment was 27 °C ± 4.8 and the mean relative humidity was 70.1% ± 11.4. Plants were given salinity treatments in two series of experiments.

Experiment 1

Plants were grown in salinity maintained at 2.5 mS cm⁻¹ (control), 5.5 mS cm⁻¹ (by adding 500ppm Na⁺ to the control) and 8.5 mS cm⁻¹ (with addition

of 1550 ppm Na⁺ to the control). Five plants were grown in each of the NFT troughs, representing one replicate, with one nutrient solution tank per replicate (Jarret and Chanter 1981). The basic salinity of 2.5 mS cm⁻¹ was achieved by the addition of equal amounts of stock solutions A and B (Table 1) to the catchment tank. Since the relative nutrient concentration was not monitored, the nutrient solution in the catchment tank was changed once a week to avoid any ion imbalance.

TABLE 1
Composition of the stock salt solutions used (Varley and Burrage 1981).

Stock Solution A	kg/100 liter
Potassium nitrate	8.30
Magnesium nitrate	3.27
Potassium dihydrogen orthophosphate	2.07
Potassium sulphate	3.67
Iron chelate	0.40
Vytel chelate mix	0.58
Stock Solution B	
Calcium nitrate	4.33

Experiment 2

Plants were exposed to the following salinity treatments :

- S1 = continuous low salinity (2.0 mS cm⁻¹),
- S2 = continuous high salinity (8.5 mS cm⁻¹),
- S3 = a change from low salinity (2.0 mS cm⁻¹) to high salinity (8.5 mS cm⁻¹) at flowering of second fruit truss;
- S4 = a change from high salinity (8.5 mS cm⁻¹) to low salinity (2.0 mS cm⁻¹) at flowering of second fruit truss.

The treatments were arranged in a completely randomized design with three replicates per treatment. Plants were selected for uniformity when the first truss became visible. Selected plants were transferred to NFT troughs and grown in recirculating tap water for 4 d prior to the salinity treatment. Initial stem height, diameter and leaf number were recorded before the start of the treatment. The top of the plants was removed above the third leaf trusses. At the end of the experiment, the dry weights of leaf, stem and roots were determined after oven-drying at 80°C for 48 h.

Leaf water potential was recorded using a pressure chamber; and diurnal measurements of stomatal conductance were determined using a continuous flow porometer (Burrage 1987, *personal communication*). The determination of stomatal conductance was performed on the lower surface of the leaves since there was no significant difference in stomatal conductance when measurements were made on the upper surface of leaves. Measurements of leaf photosynthetic rate, stomatal conductance and transpiration rate were carried out using a closed system Infra Red Gas Analyser (ADC2-The Analytical Development Co Ltd., Hoddesdon, England). Young fully expanded leaves which had been exposed to full light were chosen for the determinations. At least five readings were taken on different leaves from different plants for each treatment.

RESULTS AND DISCUSSION

Increasing the salinity significantly reduced ($P < 0.05$) the diameter and dry weight of stem. Leaf dry weight was also significantly reduced in high salinity (Table 2a, b). Root dry weight was

significantly greater with increased salinity. The reduction in stem and leaf growth could be attributed to the high salinity inducing a water deficit in the plants. The plants grown in high salinity had difficulty in absorbing water as indicated by the reduction in leaf water potential and plant water uptake (Table 3 and Fig. 3). There was an increase in leaf dry weight in plants grown initially in high salinity followed by exposure to low salinity at the later stage of growth as observed in the second experiment (Table 2b). This was associated with a recovery in plant water uptake which was similar to, or higher than, that of plants grown in the continuous low salinity. These results are consistent with the findings of Rawson and Munns (1984) who reported an increase in the rate of leaf expansion of *Helianthus annuus* upon removal of high salinity compared to plants grown continuously in low salinity. They speculated that the phenomenon was due to the utilization of assimilates regulated by the salt concentration within the roots. In their experiments, the concentrations of Na^+ and Cl^- decreased rapidly in the root cells when NaCl was removed from the nutrient solu-

TABLE 2
Plant vegetative characters at (a) continuous/constant salinities and (b) at continuous and altered salinities 2a

2a		Salinity (mS cm^{-1})			LSD 5%
Plant vegetative characters	2.5	5.5	8.5		
Plant height (cm)	93.50	91.40	90.00	ns	
Stem diameter (cm)	1.54	1.44	1.28	0.02	
Stem dry weight (g/plant)	31.24	29.33	23.07	1.44	
Leaf dry weight (g/plant)	87.50	69.82	67.75	2.36	
Root dry weight (g/plant)	17.00	22.30	28.30	0.02	
Root : shoot ratio	0.19	0.33	0.41		

2b		Salinity (mS cm^{-1})			LSD 5%
Plant vegetative characters	2.5	8.5	2.5 changed to 8.5	8.5 changed to 2.5	
Plant height (cm)	88.70	81.90	87.70	86.60	3.36
Stem diameter (cm)	1.72	1.45	1.58	1.56	0.05
Stem dry weight (g/plant)	25.28	23.04	23.31	24.20	ns
Leaf dry weight (g/plant)	54.49	49.48	51.90	55.62	3.13
Root dry weight (g/plant)	13.41	21.34	14.69	17.43	1.82
Root : shoot ratio	0.24	0.50	0.31	0.35	0.05

TABLE 3

Effects of different salinity levels on leaf water potential (ψ_w), stomatal conductance (gs), photosynthesis rate (Pn) and plant water uptake 21 and 42 d after the start of the treatments

	Salinity (mS/cm)			
	2.5	5.5	8.5	LSD 5%
ψ_w (MPa)				
21 d	-0.54	-0.63	-1.04	0.07
42 d	-0.56	-0.59	-0.95	0.08
gs (mmol/m ² /s)				
21 d	404.80	361.40	207.20	61.80
42 d	419.20	403.80	210.80	37.20
Pn (umol/m ² /s)				
21 d	4.97	4.93	4.84	ns
42 d	7.05	6.82	6.88	ns
** Plant water uptake (1/plant/day)	1.09	0.88	0.70	0.06

**Means from 7 days of determinations at the fifth week after changes in salinity.

tion. Meiri and Poljakoff-Mayber (1970) reported a similar recovery in leaf expansion rates in *Phaseolus vulgaris*. Terry *et al.* (1983) stated that plants may recover rapidly from salt stress when salts were removed. This was shown by an immediate increase in leaf expansion rate when sugar beet was transferred from a saline medium to half-strength Hoagland's culture solution. The response was due to a large increase in water potential at the root medium which was transmitted to the leaf. Kramer (1950) indicated that movement of water through roots of previously wilted plants was greater than that for the unwilted control. The production of active new roots during the recovery period could likely be attributed to such response.

Fig. 1 shows the diurnal variation of leaf water potential and stomatal conductance before and after change in the salinity. Leaf water potential of plants grown in high salinity declined to the lowest value of -1.2 MPa but recovered almost to predawn value (-0.5MPa) at 1930 hr. Stomatal conductance was highest in plants grown in low salinity, reaching 14.5 mm s⁻¹ at midday (Fig. 1a). Transfer of plants from low salinity to high salinity reduced leaf water potential and stomatal conductance to a level similar to, or lower than, the plants grown in continuously high salinity (Fig. 1b,2). The leaf water potential and stomatal conductance increased when plants were transferred from high to low salinity (S4) which suggested that they were able to recover from the salt stress imposed at the earlier stage of plant

growth. Total plant water uptake was significantly higher ($P < 0.01$) in plants grown continuously in low salinity (S1) and in plants transferred from high to low salinity (S4) than in other salinity treatments. Total plant water uptake was 26.2% and 17.5% and 6% less in S2, S3 and S4 respectively compared to continuous low salinity (S1). Cumulative plant water uptake (Fig. 3) shows an increase in water uptake following transfer from high to low salinity (S4) and the new level was not significantly different ($P > 0.05$) from that in continuously low salinity (S1). In S3, water uptake remained high for the first week after the change, but it declined to a level lower than that in continuous high salinity (S2) in the later period of plant growth (Fig. 3).

There was a clear trend towards an increase in stomatal conductance 20 d after the change of salinity from high to low (S4) (Fig. 2). Lowest stomatal conductance was recorded on plant grown in continuous high salinity (S2); however this reduction was not significant ($P > 0.05$) compared to the stomatal conductance of plants transferred from low to high salinity (S3) on all measuring dates. There was no consistent trend in the changes of leaf photosynthesis rate resulting from altered salinity. There was also no difference in leaf water potential between plants grown in low salinity (S1) and those transferred from high to low salinity (S4). However, both treatments showed a significantly higher ($P < 0.01$) leaf water potential than those in continuous high salinity (S2) and those transferred from low to high salin-

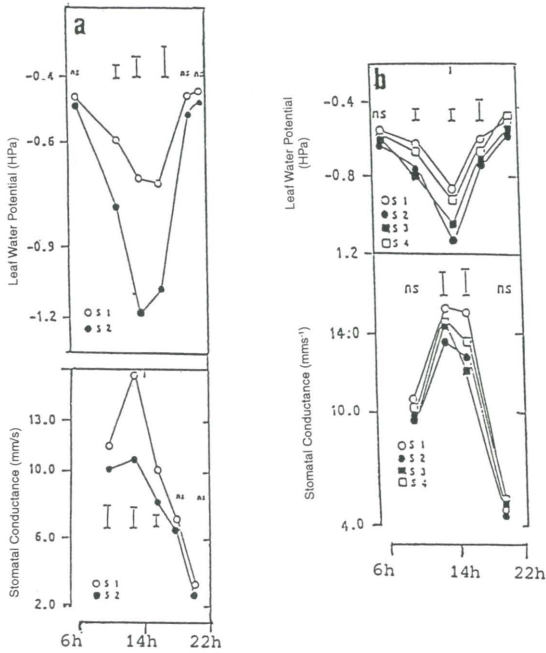


Fig. 1: Effects of salinity on diurnal changes of leaf water potential and stomatal conductance. Figure (1a) shows diurnal changes of leaf water potential and stomatal conductance, and (1b) after altering the salinity. S1 : continuous low salinity. S2 : continuous high salinity. S3 : low salinity changed to high salinity. S4 : high salinity changed to low salinity

ity (S3) on all measuring dates (Fig. 2). Stomatal conductance of S4 plants measured three days after the alteration of the salinity from high to low remained lower than that of plants grown in continuous low salinity (S1). However, when measurements were made after 20 d, stomatal conductance was higher than the plants grown in continuously low salinity (Fig. 2). The trend towards an increase of stomatal conductance when plants were subjected to a period of low salinity following exposure to high salinity, is consistent with findings by Fischer *et al.* (1970). They suggested that the over recovery of stomatal conductance was due to the physiologically 'younger' condition of these plants following turgor recovery. The generation of a physiologically 'younger' condition after a period of stress was suggested earlier by Gates (1955 a,b). Kleinendorst (1975) suggested that the rapid growth following a period of water deficit resulted from the elongation of existing cells. Dumbroff and Cooper (1974), however, showed a deleterious effect of salt on tomatoes when plants were exposed to high salinity at the seedling stage - that the growth remained se-

verely restricted following the removal of salt stress. Plants that were stressed at a later stage of growth resumed growth at a similar rate to that of the control as soon as the salt stress was removed.

In high salinity, the plants suffered an immediate reduction in stomatal conductance (Table 2 and Fig. 2). However, high salinity did not seem to significantly affect photosynthesis as there was no reduction in photosynthetic rate per unit leaf area (Fig. 2). It seems likely that high salinity influenced photosynthesis through an overall effect on surface area for CO_2 assimilation

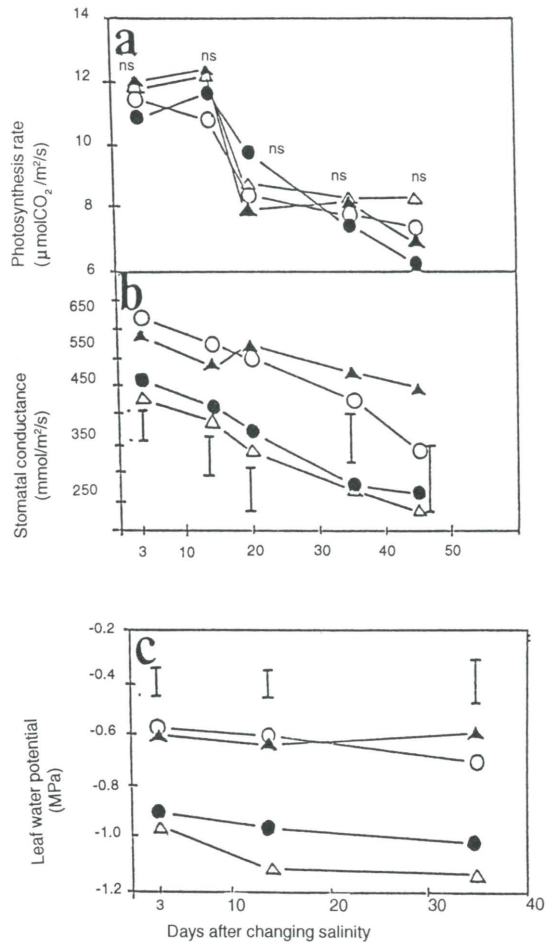


Fig. 2: Photosynthesis rate (a) stomatal conductance (b) and leaf water potential (c) as influenced by salinity. Bars represent LSD 5%

- S1 ○ = Continuous low salinity;
- S2 △ = continuous high salinity;
- S3 ● = a change from low to high salinity;
- S4 ▲ = a change from high to low salinity.

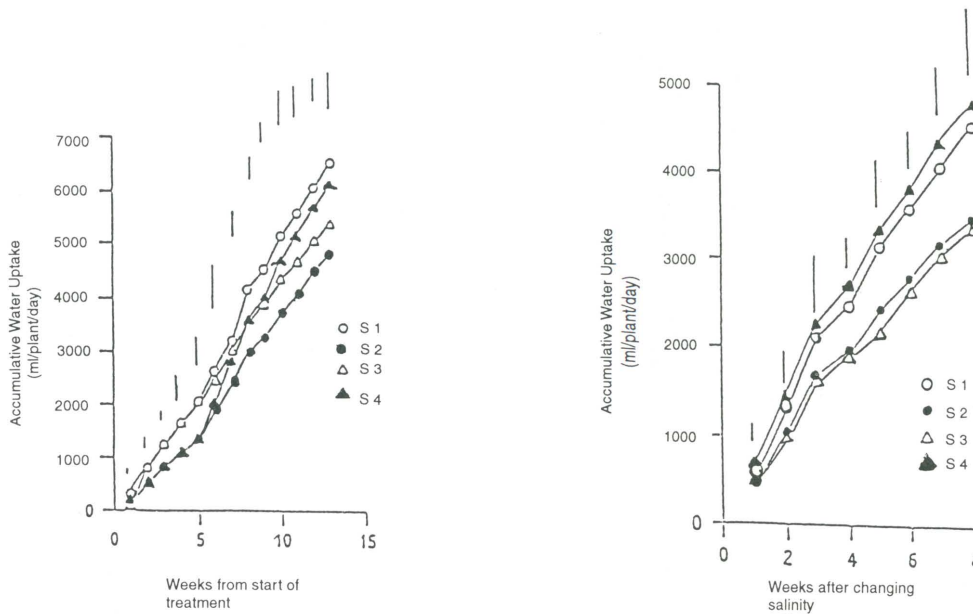


Fig. 3: Accumulative plant water uptake as influenced by salinity. Bars represent LSD 5%. S1: Continuous low salinity. 2: Continuous high salinity. S3: low salinity changed to high salinity. S4: high salinity changed to low salinity

rather than on the photosynthetic rate per unit leaf area. Several other investigators reported similar response (Papp *et al.* 1983; Taleisnik 1987). Terry and Waldron (1984) showed that photosynthetic rate expressed per unit chlorophyll was reduced upon increasing the salinity, but photosynthesis rate per unit leaf area was unaffected. They suggested that this response was probably due to an increase in the amount of photosynthetic apparatus per unit leaf area of thicker leaves, compensated for by a lower internal CO₂ concentration. Earlier, Gauch and Eaton (1942) indicated that high salinity affected the utilization of photosynthate rather than the rate of photosynthesis. This report was supported by Nieman and Clark (1976) who indicated that the reduction in growth when plants were grown in high salinity was due to a disturbance in the transport of carbohydrates rather than to a reduction in the rate of photosynthesis. The results of the present study, however, contradicted the findings of several other investigators (Gale *et al.* 1967; Jensen 1975; Cerda *et al.* 1979; Downton 1977, Seemann and Critchley 1985) who reported that the reduction in photosynthetic rate was associated with the reduction in stomatal conductance when plants were exposed to high salinity.

CONCLUSION

The restriction in the movement of water from root to shoot contributed to the reduction in leaf growth of plants grown in continuously high salinity. Altering from high to low salinity resulted in a recovery of stomatal conductance and plant water uptake to values similar to, or higher than, those found in plants that were grown continuously in low salinity. Subsequently, this has also resulted in an increase in leaf growth. It is evident that although stomatal conductance was affected by the changes in salinity, this effect did not bring about similar changes in the photosynthetic rate. In hydroponics, regulation of salinity level in the root environment to regulate the growth of the shoot can be easily achieved. Thus, an understanding of the effects of changes in salinity is important for improving fruit quality without reducing yield.

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