Review

Adverse Effects of Salinity on Citrus

ADNAN AL-YASSIN

National center for Agricultural Research and Technology Transfer, P.O. Box 639, Baqa 19381, Jordan
Corresponding author's e-mail: a.yassin@ncartt.gov.jo

ABSTRACT

Due to the rapid expansion of irrigated agriculture, efficient use of the limited water resources in arid and semi-arid regions is becoming more and more vital. However, water salinity is a major problem due to its negative influence on the yields of many crops. It reduces citrus trees' growth and causes physiological disorders. Salt-stress lowers net CO_2 assimilation, stomatal conductance, and water potential of citrus tree leaves, in addition to accumulation of excessive concentration of chloride or sodium in leaves. A great deal of research indicates that citrus have the genetic potential to be salt-sensitive. However, inheritance studies in citrus are scarce. In this paper, the adverse of effects of salinity on physiological aspects of citrus are reviewed. The review summarizes the current state of knowledge about the responses and tolerance of citrus trees to salinity.

Key Words: Citrus; Irrigation; Salinity; Rootstock-scion interaction

INTRODUCTION

Due to the rapid expansion of irrigated agriculture, efficient use of the limited water resources in arid and semi-arid regions is becoming more and more vital. However, water salinity is a major problem due to its negative influence on the yields of many crops. Except for halophytes, water salinity partially inhibits the growth of most plants. Four reasons that are usually introduced as solely responsible for reduction of plant growth under salt-stressed conditions are briefly the (i) Osmotic stress caused by reducing the availability of external water, (ii) Specific ion toxicity effects caused by metabolic processes in the cell, (iii) Nutritional imbalance caused by these ion-toxicity effects, and (iv) A combination of any two of the above-mentioned factors. Citrus is salt-sensitive. Its response to salinity depends on several factors like rootstock - scion combinations, irrigation system, soil type and climate, etc.

Changing one or more of these factors (with the same irrigation water) could produce entirely different results. Similar to most other plants, salinity reduces citrus trees' growth and causes physiological disorders. For instance, salt-stress lowers net CO_2 assimilation, stomatal conductance, and water potential of citrus tree leaves. These effects are associated with accumulation of excessive concentration of chloride or sodium in leaves, in addition to reduction of cell size and foliar damage. The accumulation of chloride in leaves occurs only above a certain threshold of irrigation water salinity. It is rootstock dependent. Accumulation of Sodium in shoots and leaves is more scion-dependent (Banuls *et al.,* 1990). When data on relative yields of citrus, expressed in relation to the controlled treatment, were plotted against soil salinity paste extract (ECe), it indicated tolerance threshold values of different rootstock-scion combinations and yield decline for each salinity unit increase. However, few studies provide information on fruit-yield responses. In Citrus, it is not known whether salt-tolerance during germination or seedling emergence is related to tolerance during later stages of growth. But in the presence of adequate concentration of calcium in saline irrigation water, calcium ameliorates the effects of saline conditions on the growth of plants, thus the plants could withstand the effects of relatively high salinity concentration. Internal ion concentrations were determined in an attempt to reveal the mechanisms through which citrus cells tolerate salinity. It was concluded that the internal levels of K^+ play an important role in these mechanisms.

Several papers describe salt-induced changes in various proteins. Both short-term and long-term changes have been reported for several salt-affected citrus cells. The variations in mechanisms and proteins involved in salt-tolerant cells of citrus were attributed to many factors. In areas where soil salinity is a serious problem, "phytophthora root rot" of citrus was observed to be usually severe. Thus, salinity stress could make the "phytophthora root rot" phenomenon more severe. While inheritance studies in citrus are scarce, wide segregation has been noted for some characteristics, suggesting a proposal to breed new salt excluding rootstocks.

The objective of this paper is to summarize the prevailing state of knowledge about the responses and tolerance of citrus trees to salt stress.

Response of Citrus to Salinity

Growth and yield. All soils and irrigation waters contain soluble salts, many of which are required for plant normal growth and development. However, many soils and waters, particularly in semi- arid irrigated areas, contain excessive amounts of salts that could become harmful to plants. Studies concerning growth and yield reduction due to excessive salinity are difficult to extrapolate to the sub-tropical conditions, because summer rains reduce soil salinity by leaching accumulated salts from the root zone of the trees (Boman, 1993).

Plants' capacity to endure the effects of excessive salt in the rootzone is the "salt tolerance" of plants. The range

of salt concentrations tolerated by crops varies greatly from species to species (Maas, 1990). Citrus, as well as other tree species are particularly more sensitive to salinity than many other crops (Banuls *et al.,* 1990; Boman, 1993; Maas, 1993, 1990; Zekri, 1990a, 1993a). The observed effects of salinity are various symptoms of leaf injury, growth suppression and yield decline. Suppression of plant growth under salt-stress is usually attributed to (a) osmotic stress, due to lowering external water potential, (b) specific ion effect on metabolic processes in the cell. The two effects are not usually mutually exclusive (Ben-Hayyim *et al.,* 1987).

Changing some of the factors like rootstock - scion combination, irrigation system, soil type and climate (with the same irrigation water) could produce entirely different results. The mechanisms operating in the survival of various salinity-stressed plants are either (i) The accumulated ions by these plants in response to high concentrations of salts in their environment, or (ii) The 'plants' excluding salts and producing high concentration of organic molecules to protect themselves by lowering the osmotic potential of cells (Ben-Hayyim, 1985). Cell culture has adopted the first mechanism as the one at work.

Salinity reduces stomatal conductance in citrus trees (Banuls & Primo-Millo, 1992, 1995; Zekri & Parsons, 1990a; Zekri & Parsons, 1990c), transpiration, hydraulic conductivity of roots and evapotranspiration (Syvertsen & Graham, 1985; Zekri, 1991a; Zekri & Parsons, 1989, 1993c) fibrous root dry weight (Lea-Cox & Syvertsen, 1993), long-term nitrogen use efficiency (mg d. Wt mg N^{-1}), root density (Alva & Syvertsen, 1991), CO_2 assimilation (Garcia-Legaz *et al.,* 1993; Banuls & Primo-Millo, 1995), water potential in leaf gas exchange (Banuls & Primo-Millo, 1992, 1995; Zekri & Parsons, 1990c), shoot elongation, relative growth rate , shoot: root ratio (Ben-Hayyim *et al.,* 1989), germination or emergence (Zekri, 1993a, 1993b, 1993c) and water-use efficiency (Lea-Cox & Syvertsen, 1993). These effects were associated with an accumulation of excessive concentrations of Cl^- in leaves (Banuls & Primo-Millo, 1995).

Rootstocks differ in their ability to restrict uptake and/or transport of Cl^- and Na^+ to scions (Banuls *et al.,* 1990; Banuls & Primo-Millo, 1992). Salt-tolerant crop is associated with salt exclusion, ability to restrict uptake and/or transport of salts between roots and shoot (Banuls *et al.,* 1990).

The reduction in relative growth and sodium accumulation in shoots by salt treatment was more scion dependent, whereas defoliation and chloride accumulation in shoots was more rootstock dependent. The main ions causing injuries are chlorides, and the salt tolerance of some citrus rootstocks is determined by their capacity for chloride excelsior (Banuls *et al.,* 1990). When reductions in fruit yield occur without excessive accumulation of Cl^- or Na^+ and without any apparent toxicity symptoms, it is indicated that the dominant effect is osmotic stress (Cerda *et al.,* 1990;

Dasberg *et al.,* 1991).

Cerda *et al.* (1990) studied salt tolerance of 'Verna' lemon trees budded on macrophylla rootstocks, whereas sour orange and Cleopatra mandarin were budded with Sanguina orange scions to avoid overgrowth and a year later with 'Verna' lemon scions. Irrigation water treatments were applied to circular basins around each tree of three meter diameter. Four water salinity levels were used, 4, 11, 26.5 and 42.5 mol m^{-3} of Cl^- (The chemical compositions of irrigation waters are shown in Table I). These Cl^- concentrations were diluted by rainfall. The final concentrations after dilution were 2.5, 6.98, 16.83 and 26.99 mol/mL^{-3} of Cl^-, respectively.

Significant effect of salinity and rootstock on growth and fruit yield were found on the growth and yields of 'Verna' lemon trees (Table II). The growth of trees on all rootstock was depressed by increasing salinity in the root zone. This effect is more marked on those trees on Cleopatra mandarin and macrophylla rootstocks than those of sour orange rootstock. Yields of 'Verna' lemon trees on sour orange rootstock decreased, comparing treatments S_1, and S_4, was 37%, whereas on the other rootstock 'Verna' lemon trees yield decreased by 46 and 56% on Cleopatra mandarin and macrophylla, respectively.

The fruit yield reduction was associated primarily with a decrease in the number of fruits per tree rather than to differences in weight per fruit. (Cerda *et al.,* 1990; Dasberg *et al.,* 1991). Fig. 1 shows the relative yield for each combination, expressed in relation to the control treatment, plotted against EC_e. The tolerance threshold values according to a piece-wise-linear response function were: 1.53, 2.08 and 1.02 dS m^{-1} for sour orange, Cleopatra mandarin and macrophylla, respectively. The yield decrease for each dS m^{-1} increase in mean soil salinity above the threshold levels was lowest for sour orange 10.5 as compared with Cleopatra mandarin and macrophylla 13.7 and 14.2%, respectively. These were calculated from the data of Table II.
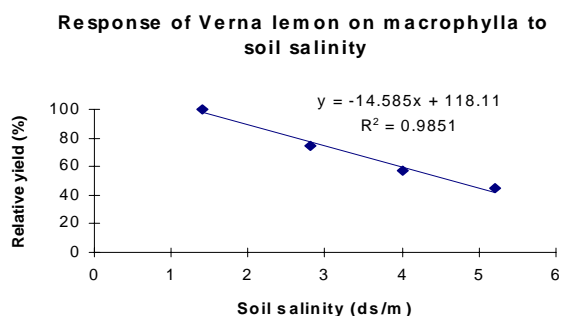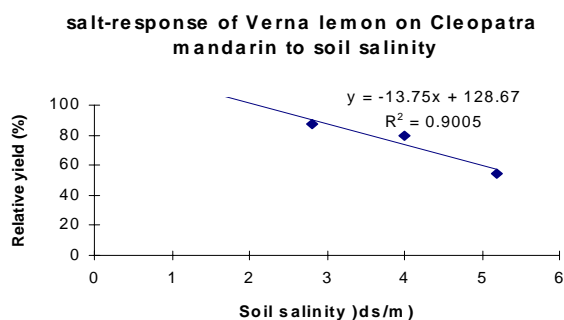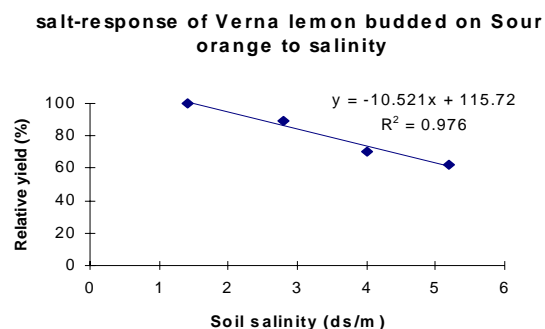
Dasberg *et al.* (1991) reported that salinity and water stress have similar effects on plant growth. Increasing chloride concentration in irrigation water treatments (2.68, 7.72 and 12.79 mol m^{-3} Cl^-) during the experimental period, decreased the average total growth of Shamouti orange.

The fruit yield was decreased by salinity. However, the average fruit yield over the six-year experimental period did not show any significant effects of treatments. The average EC_e values for the Cl_1, Cl_2 and Cl_3 treatments were 2.0, 2.8 and 3.4 dS m^{-1}, respectively. And the average relative yields were 100 for the control, 86.5 and 81.1% respectively. So the threshold value is 2.61 dS m^{-1} and the relative yield decrease per unit salinity increase is 8.73%.
$$Y = 100 - 8.73 (EC_e - 2.61)$$

The tolerance limit of salinity in the rootzone for 'Valencia' oranges was estimated at an ECe of 2.5 - 3.0 dS m^{-1}. Maas (1993) reported that the growth of citrus species and their fruit yield generally reduced at soil electrical

Table I. Chemical composition of irrigation waters

Salinity treatment	Cl⁻ mol/m³	SO₄²⁻	HCO₃⁻	Ca⁺	Mg²⁺	Na⁺	EC	SAR
S_1	4	2.9	2.2	2.2	2.3	3.9	1.2	1.8
S_2	11	3.7	2.2	1.8	2.2	11.5	2.2	5.8
S_3	26.5	3.7	2.2	1.9	2.3	27.8	3.8	13.6
S_4	42.5	3.7	2.2	1.9	2.4	43.5	5.3	21.0

Source: Cerda *et al.* (1990)

Fig. 1. Relative fruit yield of lemon as a function of increasing soil salinity. Threshold and slope values are: 1.49 and 10.5 for sour orange, 2.08 and 13.7 for Cleopatra mandarin, 1.24 and 14.5 for macrophylla

salt-response of Verna lemon budded on Sour orange to salinity

$y = -10.521x + 115.72$
$R^2 = 0.976$

salt-response of Verna lemon on Cleopatra mandarin to soil salinity

$y = -13.75x + 128.67$
$R^2 = 0.9005$

Response of Verna lemon on macrophylla to soil salinity

$y = -14.585x + 118.11$
$R^2 = 0.9851$

conductivities (ECe) above 1.4 dS m⁻¹ (Maas, 1990). Maas (1990) concluded that the ECe threshold for oranges was 1.7 dS m⁻¹ in the root zone while each additional 1.0 dS m⁻¹ would decrease yield by 16%. Salinity, not only reduced growth and yield due to the osmotic potential effect, but for the same reasoning salinity delayed and depressed

Table II. Growth and yield of Verna lemon in relation to salinity and rootstock

[Cl⁻] in the irrigation (mol/m³)	increasing trunk circumference (Cm)	Yield (Kg/tree)						Mean number of fruit / tree/ year
		1985	1986	1987	1988	1989	mean	
Sour orange - sanguine orange - Verna Lemon								
4	15	11	37	34	76	96	51	340
11	12	15	31	32	67	82	45	331
26.5	10	7	25	31	59	57	36	267
42.5	13	11	17	29	58	45	32	248
Cleopatra mandarin - Sanguina orange - Verna lemon								
4	18	14	26	27	88	84	48	377
11	14	6	22	31	70	80	42	335
26.5	13	9	27	31	64	61	38	330
42.5	12	5	15	19	48	45	26	245
Macrophylla - Verna lemon								
4	10	25	53	55	101	81	63	501
11	10	19	46	37	84	48	47	336
26.5	7	13	37	35	61	33	36	253
42.5	6	22	60	24	42	14	28	199

Source: Cerda *et al.*, 1990.

emergence, reduced shoot and root biomasses (Zekri, 1993b). However, the beneficial effect of (Ca²⁺) addition to the saline irrigation water is valid during emergence. The addition of 5 mol m⁻³ CaSO₄ to the saline solution (50 mol m⁻³ NaCl) enhanced the emergence of first seedling in many rootstocks studied, and improved the final emergence of other stocks. No uniform trend was found, however, between salt tolerance during emergence and that during seedling growth (Zekri, 1993a).

Although reduced emergence in NaCl solution appeared to be mostly due to osmotic effect, there was also evidence of toxic effect of NaCl, because the addition of Ca²⁺ increased seedling emergence of some rootstocks.

Specific ion toxicity. The impact of specific ions depends on the ability of rootstocks to restrict their transport to the scions. Differences in Cl⁻ transport properties and tolerance of different rootstocks are apparent in lemon (Cerda *et al.*, 1990). Cole (1985) applied four salinity levels (range 2 to 5 meq L⁻¹ Cl⁻) to mature orange trees grown on Rough lemon rootstock, to assess the effects of salinity. The treatments resulted in soil salinities of 0.9 to 1.5 dS m⁻¹. Although these salinities are less than threshold, yield decrement of about 20% above a threshold level of about 4.3 meq L⁻¹. These yield decrements were due to chloride toxicity rather than osmotic stress, for osmotic effect soil salinity needs to exceed the threshold value (Fig. 2). Ben-Hayyim *et al.* (1987) found that the growth of both non-selected and NaCl tolerant cell lines of Shamouti orange was inhibited by CaCl₂ and PEG. At a given osmotic potential CaCl₂ was a stronger inhibitor than NaCl and PEG was the least toxic (Zekri & Parsons, 1990c; Zekri, 1990a). The thresholds value of PEG is 0.052 MPa, and it is 0.013 and 0.033 MPa for NaCl and CaCl₂, respectively (Fig. 3).

Polyethylene Glycole (PEG) is a non-ionic organic compound used to stimulate water stress effect in plants. Although PEG-6000 has toxic effect associated with heavy metals (AL & Mn), these heavy metals are not detected yet (Zekri & Parsons, 1990a). Comparison of the effect of NaCl

and $CaCl_2$, on the basis of equal osmotic potentials indicates lower levels of internal K in the presence of $CaCl_2$ than NaCl, at the range above 20 meq L^{-1} $CaCl_2$ in the median. Ben-Hayyim *et al.* (1985) found that replacement of NaCl by KCl had a more pronounced inhibitory effect. Replacement of Na_2SO_4 by K_2SO_4 had an inhibitory effect on all four NaCl-tolerant lines, although of a lesser extent than KCl tolerant lines (Fig 4).

Boman (1993) reported a reduction in canopy volumes of 'Ruby Red' grapefruit budded on four rootstocks (Sour

Fig. 2. Effect of irrigation water salinity on yield of Washington Navel Oranges on Rough Lemon rootstock

Chloride toxicity in citrus
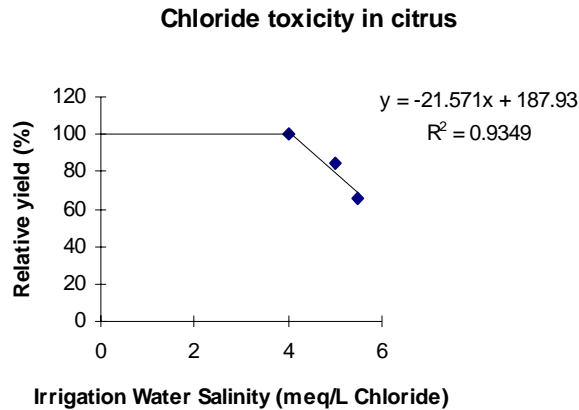
Fig. 3. Relative growth of salt-tolerant cells as a function of increasing NaCl, CaCl2, and PEG concentrations
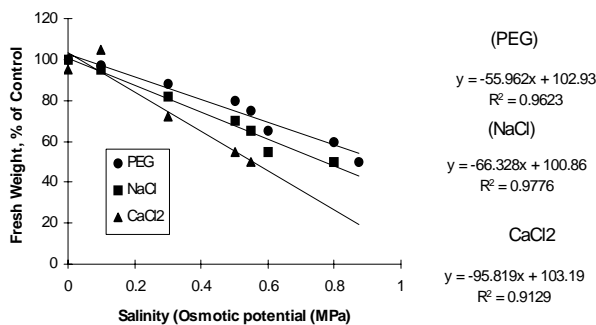
Fig. 4. Effect of increasing external PEG. NaCl and CaCl2 concentration on internal K concentration in salt-tolerant cells
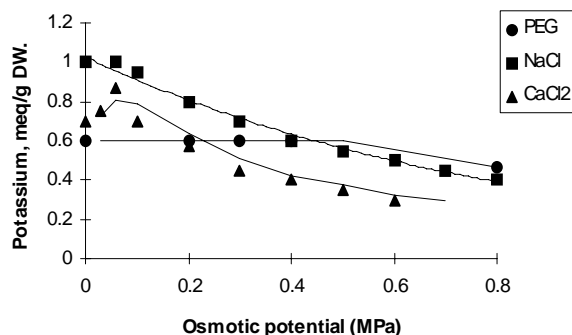
orange (SO), Carrizo citrange (CA), Cleopatra mandarin (CL), or Swingle citrumelo (SW) (Table III). Irrigation water had electrical conductivities 0.7, 2.3, 3.9, or 5.5 dS m^{-1}. The reduction in canopy volume was about 7% for each 1 dS m^{-1} increase in irrigation water salinity level above the base level of 0.7 dS m^{-1}. Salinity results in Cl^{-} accumulation to toxic levels in leaves. Alva and Syvertsen (1991) reported 0.2% Cl^{-} concentration level in leaves as the toxic level on Carrizo but not on Sour orange rootstock. Cole (1985) suggested that irrigation water salinities above 4.3 meq L^{-1} chloride yield losses might be expected due to toxic effects of Chloride rather than Osmotic effect. And 20% yield decrement / 1 meq L^{-1} Chloride in the irrigation water above the threshold level of about 4.3 meq L^{-1}.

The leaf Chloride concentration range 0.2 to 1.2% of Valencia orange on Rough lemon suggests that Rough lemon is a poor chloride excludes. Zekri and Parsons

Table III. Mean change in trunk cross- sectional area and December 1989 canopy volume by water salinity for each rootstock

Parameter	EC$_{iw}$ (ds/m)	Rootstock Carrizo Citrange	Cleopatra mandarin	Sour orange	Swingle citrumelo	Mean
Canopy	0.7	19.1	23.4	8.9	19.0	17.6
Volume	2.3	13.0	19.2	8.5	17.3	17.5
Dec.1989	3.9	13.1	17.3	6.5	17.0	12.73
(ft^3)	5.5	11.4	16.5	5.6	12.7	11.55

Data from Boman (1993)

Table IV. Mean leaf Cl and Na contents by irrigation water Salinity for each rootstock

Parameter	Water Salinity ds/m			Rootstock		
		CC	CM	SO	SC	Mean
CL (%)	0.7	0.70	0.18	0.27	0.38	0.3825
	2.3	0.88	0.21	0.38	0.44	0.4772
	3.9	1.26	0.29	0.61	0.61	0.6925
	5.5	1.53	0.63	1.07	0.73	0.990
Na (%)	0.7	0.047	0.050	0.063	0.063	0.0557
	2.3	0.053	0.057	0.073	0.057	0.06
	3.9	0.083	0.090	0.133	0.073	0.0947
	5.5	0.090	0.143	0.187	0.143	0.1407

Source: Boman (1993)

Fig. 5. The change in leaf Cl concentration relative to irrigation salinity level for trees on Carrizo citrange (CC), Cleopatra mandarin (CM), sour orange (SO), and Swingle citrumelo (SC) rootstocks
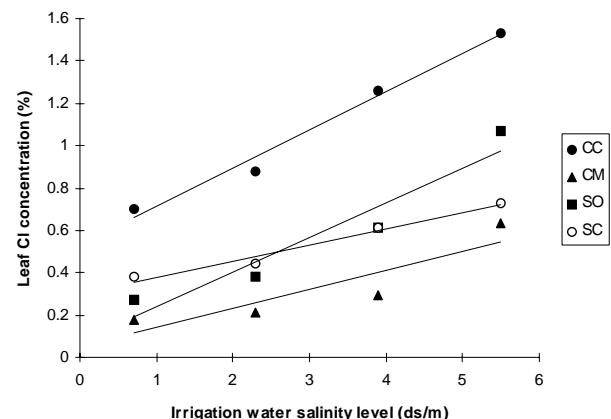
(1990b) reported that in the literature relative yield reduction of 1.4% for each 1 meq L^{-1} increase in Cl^- concentration of the soil solution extract, above a threshold value of 4.5 meq L^{-1} is observed. Leaf tissue analysis showed that chloride toxicity, consisting of necrotic areas on leaf margins, was one of the most common visible salt injuries. Leaf Chloride concentration was directly related to irrigation water salinity level (Table IV).

The trees on Carrizo citrange rootstock accumulate more Cl^- than trees on other rootstocks (Fig. 5). The Cl^- accumulation of trees on (CC) at 0.7 dS m^{-1} salinity level was greater than that for trees on (CM) and (SC) rootstocks at the 5.5 dS m^{-1} level. Toxicity symptoms usually appear when leaf Cl^- levels reach about 1% of leaf dry weight. Based on reduction in yield, the Cl^- leaf concentration as low as 0.2% can be considered excessive.

Leaf Na^+ concentration of grapefruit trees on all rootstocks had levels ranging from 0.05 - 0.06% with the salinity of irrigation water ranging from 0.7 - 5.5 dS m^{-1} water (The linear relationship is $Y = 0.2409 + 0.1272$ (EC_{iw})) as shown in Fig. 6. Although trees on Carrizo citrange accumulated the highest Cl^- levels, they were most effective at excluding Na^+, with average leaf Na^+ contents of 0.09 at the 5.5 dS m^{-1} salinity level (Boman, 1993). Toxicity levels appear when leaf Na^+ level reach 0.10- 0.25% of leaf dry weight [linear relationship with salinity $Y= 0.0316 + 0.0181(EC_{iw})$]. Syvertsen *et al.* (1988) showed that high Na^+ in leaves can be physiologically more determinable than excess Cl^-.

Banuls *et al.* (1990) studied the uptake and distribution of chloride and sodium in 'Navel' orange and Clementine (CL) scion on Cleopatra mandarin (CM) and Troyer citrange (TC) rootstocks. Plants were supplied with saline solution containing 0-60 mM NaCl. They concluded that relative growth reduction caused by salt treatment was more scion-dependent, whereas defoliation was more rootstock-dependent.

Scions on Cleopatra mandarin accumulated less chloride in their leaves and roots than did scions on Troyer citrange. However, sodium content was lower in scions on Troyer citrange (TC) than Cleopatra mandarin (CM). When scions were compared, the decrease in relative weight is marked in plants grafted with 'Navel' orange than in Clementine. The greatest growth reduction occurs in plants of 'Navel' orange grafted on Troyer citrange (the most sensitive combination).

The concentration of Cl in leaves reached values ranged from 1.1 mmol/g dry weight in Clementine/TC to 0.5 mmol/g dry weight in Clementine/CM. Sodium concentration in leaves increased by salt treatment, reaching values ranging between 0.7 and 1.0 mmol/g dry weight. Leaf Chloride level in Clemintine scions were lower than 'Navel' orange when both were grafted on the same rootstock. Sodium concentration was lower in scions on Troyer citrange than in Cleopatra mandarin (Banuls *et al.,* 1995). El-Boray *et al.* (1988) reported that the accumulation

of sodium in leaves of sour orange increased when exposed to increasing salinity level (370-6000 mg L^{-1}). However; no results were reported by El-Boray about either the chloride concentration in leaves or about the attributable reason for Na^+ accumulation in the leaves of sour orange seedlings.

Nutritional Imbalance

Nitrogen (N). One important variable often overlooked in evaluating the effect of salinity on plants is the Na^+: Ca^{2+} ratio of the saline treatment solutions. Virtually, all salinity studies deal with NaCl, either alone or in concert with other salts. Differences in Ca^{2+} concentration among studies have led to some confusion on the relative importance of Na^+, as Na^+ toxicity is usually only a problem when Ca^{2+} concentrations are relatively low (Syvertsen & Smith, 1995). However, few studies have tried to elucidate the mechanism of reduced NO_3 uptake with high Chloride concentration at the whole plant level. Banuls *et al.* (1990) indicated that N accumulation in 'Navel' orange scion on CM and Troyer citrange was negatively correlated with Cl^- accumulation during salinity stress. They speculated that this was due to some form of competition between NO_3 and Cl^- ions. However, this interpretation did not consider species differences in salinity tolerance, growth, water use or nutrient requirement which may have implicated a mechanism of reduced N uptake.

Salinity reduces water use and Nitrate-N-use efficiency of citrus. Lea-Cox and Syvertsen (1993) exposed 16 week-old seedlings of both CM and Volkamer Lemon (VL) to weekly application of 20N - 8.7 P- 16.7 K^+ nutrient solution at concentration of 212 mg N L^{-1}. Two weeks after transplanting, a salt treatment of daily increasing concentration of 3:1 NaCl: $CaCl_2$ solution was applied. The final solution, which had concentration level of EC_e of 6.13 dS m^{-1} (osmotic potential $\approx$ 0.22 MPa), was applied from third week after transplanting until final harvest four weeks later.

They concluded that Volkamer lemon seedlings were more sensitive to salt stress (as indicated by weight and the higher Cl^- content). The high N content of salinized VL mature leaves occurred in conjunction with high leaf content. There was a large decrease in N uptake however for both mature leaf and new growth tissues in both species under saline treatment. This implies that salinity would have eventually reduced the total N content of both species by reducing their growth rate. There was no evidence of Cl^- antagonism of nitrate (NO_3) uptake.

There was a stronger relationship between reduced water use efficiency and N- uptake than between (N) uptake and Cl^- content under salt stress (Lea-Cox & Syvertsen, 1993), at least after the short-term duration of this experiment. Water use was found to greatest underneath the canopy drip line and generally with increasing soil depth (Whiteny *et al.,* 1991; Alva & Syvertsen, 1991)

Banuls *et al.* (1990) showed that (N) concentrations in leaves and fibrous roots of grafted scions on Troyer citrange rootstock decreased with increasing NaCl in the irrigation

solution. There was no decrease, however, in (N) concentration when these scions had lower foliar Cl⁻ concentrations on the relatively more salt-tolerant CM. They noted that the reduction in (N) concentration in leaves and roots was closely related to the accumulation of Cl⁻ in tissues. Zekri (1991a,b) found highly significant negative correlation between N and Phosphor (P) concentrations in the leaves of two citrus cultivars.

Lea-Cox and Syvertsen (1993) found that (N) uptake in the four-week salinity was reduced, as much in CM seedlings by salt treatment as in VL seedlings, even though Cl⁻ content was significantly lower in the relatively salt-tolerant CM. They concluded that (N) uptake is not affected by salinity. Zekri and Parsons (1992) concluded that increasing salinity level would not reduce N and Ca^{2+} levels in the leaves.

Dasberg (1987) concluded that N leaching is unavoidable, since the salt-stressed citrus roots are not able to take up the entire available N in the soil. Recently, Syvertsen *et al.* (1993) hypothesized that (1) the saline irrigation water increases nutrient leaching (2) rootstock differences in salinity tolerance, water use and nutrient uptake, should be reflected in nutrient leaching losses below the rootzone. Syvertsen and Smith (1995) found that the lower requirement of N by slower growing trees on sour orange (SO) was reflected in higher leaching losses from trees on SO than from trees on 'Volkamer' lemon. On the other hand, lea-Cox and Syvertsen (1993) found that the concentrations of K^+, Ca^{2+}, and Mg^{2+} were also unaffected by salinity (even though these were in the low range), 10-14, 16-18, 1.5-1.8 mg/g, respectively).

The ability of sour orange seedlings to withstand saline irrigation could be improved by addition of calcium to the saline irrigation water (Zekri & Parsons, 1990b).

Zekri and Parsons (1990b) added various concentrations of $CaSO_4$, CaCl2 and KCl salts to 40 mM NaCl (Table V). Then, sour orange seedlings were treated for 4 months with these irrigation waters. Calcium has been shown to ameliorate the effect of saline conditions on growth of plants. This effect has been attributed to several actions of Ca^{2+} including, (i) Flocculation of the soil in which clay particles have dispersed by Na^+, (ii) Preventing the uptake of the Na^+ ion to injurious levels and allowing the uptake of K^+, and (iii) Maintaining the selective permeability of membranes. In the presence of adequate concentration of Ca^{2+}, plants exclude Na^+ and withstand the effects of relatively high NaCl concentration.

The beneficial effect of Ca^{2+} depends on the anion associated with the Ca^{2+}. Addition of $CaSO_4$, $CaNO_3$ and $CaCO_3$ could reduce Na^+ concentration in citrus leaf tissue, but neither $CaCl_2$ nor KCl should be used due to the Cl⁻ accompanying the Ca^{2+} and the sensitivity of citrus to Cl⁻, since, none of them was found to overcome the detrimental effects of NaCl by decreasing the Na^+ and Cl⁻ concentrations in citrus leaves (Zekri & Parsons, 1990b; Zekri, 1993c). Table VI and Fig. 7 show the beneficial

effect of Ca^{2+} in the saline irrigation waters which improved growth of shoots and roots. The beneficial effect of $CaSO_4$ is mainly attributed to reduction in the accumulation of Na^+ and Cl⁻ below the toxicity levels in leaves 0.4% and 0.5%, respectively (Zekri & Parsons, 1990b). It is obvious from Table VI that the addition of $CaCl_2$ reduced Na^+ but increased Cl⁻ to the toxicity levels (>0.5%) in the leaves. Addition of KCl did not reduce Na^+, increased Cl⁻, and reduced Ca^{2+} and Mg^{2+} relative to NaCl alone. However, Replacement of Na^+ ions by K^+ markedly increased the

Fig. 6. Leaf concentration (% of total dry weight) of Cl and Na in grapefruit trees at different irrigation water salinities
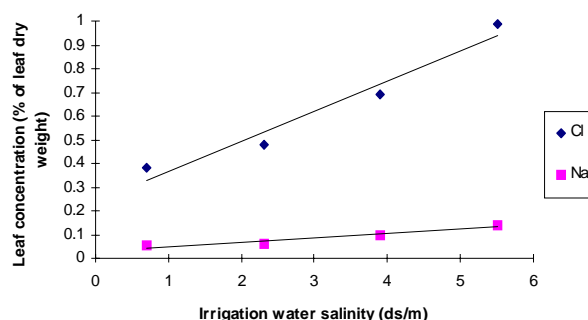
Table V. Salt additions to and physical properties of the nutrient solution (NaCl concentration was 40 mM)

Treatment	TDS	EC ds/m	Osmotic Potential (MPa)
Control (no NaCl)	0.4	0.9	-0.03
NaCl	2.8	5.0	-0.19
NaCl+ 1 mM $CaSO_4$	2.9	5.2	-0.19
NaCl+ 5 mM $CaSO_4$	3.1	5.5	-0.21
NaCl+ 7.5 mM $CaSO_4$	3.5	9.3	-0.23
NaCl+ 13.5 mM $CaSO_4$	3.8	6.8	-0.26
NaCl+ 7.5 mM $CaSO_4$	3.6	6.5	-0.24
NaCl+ 7 mM KCl	3.4	6.1	-0.23

Source: Zekri and Parsons (1990b)

Table VI. Leaf mineral concentration (% leaf dry weight) of sour orange seedlings mineral Content (%)

Treatment	Ca	Mg	Na	Cl	K
Control (no NaCl)	2.1 b	0.30 a	0.02 c	0.02 d	0.5 b
NaCl	1.7 c	0.21 b	0.47 a	0.97 b	2.0 c
NaCl+ 1 mM $CaSO_4$	1.7 c	0.22 b	0.43 a	0.48 c	2.1 c
NaCl+ 5 mM $CaSO_4$	2.4 ab	0.21 b	0.27 b	0.41 c	1.9 c
NaCl+ 7.5 mM $CaSO_4$	2.7 a	0.20 b	0.24 b	0.43 c	1.9 c
NaCl+ 13.5 mM $CaSO_4$	2.7 a	0.20 b	0.24 b	0.43 c	1.9 c
NaCl+ 7.5 mM $CaSO_4$	2.8 a	0.20 b	0.25 b	1.36 d	2.0 c
NaCl+ 7 mM KCl	1.3 d	0.15 c	0.43 a	1.21 d	3.6 a

Source: Zekri and Parsons (1990b)

Fig. 7. Relative root and shoot dry weights of sour orange seedlings after 4 months of treatment with salt solution. (NaCl concentration was 40 mM)
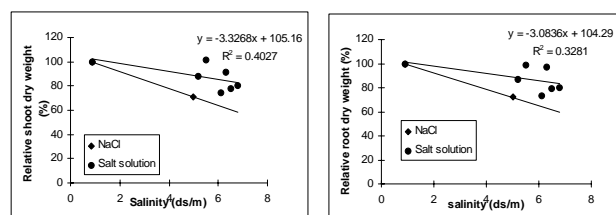
levels of K^+ with a concomitant significant decrease of growth (Fig. 8) (Ben - Hayyim *et al.,* 1985).

Ben-Hayyim *et al.* (1985) reported that exposure of NaCl-tolerant cell lines of *Citrus aurantium* to salt other than NaCl resulted in greater tolerance to Na_2SO_4, but rather poor tolerance to K^+ introduced as K_2SO_4 or KCl. The latter had stronger inhibitory effect. Behboudian *et al.* (1986) fond that Valencia orange, Tayler lemon and Ellendale tangor scions on either Cleopatra mandarin or Rough lemon had decreased K^+ concentration fraction in their leaves when exposed to Salinity in irrigation water (0-75 mM Cl⁻). Some of the adverse effects of salinity have been attributed to K^+ deficiency, but K^+ reduction in citrus leaves under salinity has not always been observed (Behboudian *et al.,* 1986). However, Zekri and Parsons (1992) observed K^+ concentration reduction in the leaves of Na^+-accumulator rootstocks (Cleopatra mandarin (CM) and rough lemon (RL)), but not in the Na^+-excluder rootstocks Swingle citrumelo (SC) and Carrizo citrange (CC).

Increasing salinity worsened nutritional imbalances; however, this effect was rootstock dependent. Banuls *et al.* (1990), Banuls and Primo-Millo (1995) found that leaves and roots of four scion-rootstock combinations showed no increase in Na^+ and a decrease in K^+, Ca^{2+} and Mg^{2+} concentrations during salt treatment. Similar results were obtained by Ben Hayyim *et al.* (1985) on *Citrus aurantium*. Alva and Syvertsen (1991), Syvertsen and Yelenosky (1988) found that K^+ concentration of Carrizo citrange trees and Mg^{2+} of sour orange tree were reduced by high salinity.

An increase in Ca^{2+} concentration in the leaf when irrigated with salinized irrigation water minimized the effect of salt-stress (Zekri & Parson, 1990a; Alva & Syvertsen, 1991; Zekri, 1993a). On the other hand, Cerda *et al.* (1995) evaluated the mineral concentration of 'Verna' lemon leaves using the Diagnosis and Recommendation Integrated System (DRIS). However, this approach failed to reveal under saline conditions if a nutrient deficiency is induced by an excess of salinity or deficient fertilization.

The decrease in Mg^{2+} concentration in leaves of salt affected trees could be attributed to the low Mg^{2+} concentration in the exchange complex. Alva and Syvertsen (1991) found that salinity not only increased soil EC_e, Na^+, Cl⁻ and Ca^{2+}, but also increased P concentration and decreased Mg^{2+}. Increasing Ca^{2+} (by addition of Ca^{2+} as gypsum $CaSO_4$) has been shown to decrease Mg^{2+} concentration, primarily due to displacement of Mg^{2+} from the soil complex.

Scion-rootstock interactions. Citrus is generally classified as a salt-sensitive crop. However, studies have indicated some differences in salt tolerance among citrus rootstocks, based on visual leaf burn symptoms and leaf Cl⁻ content (Banuls *et al.,* 1990; Boman, 1993; Maas, 1993, 1990; Zekri, 1990a, 1993a). Citrus rootstocks differ greatly in their ability to exclude Cl⁻, Na^+ or both from the scions. Numerous studies have compared the relative abilities of rootstocks to restrict salts from reaching the scions (Maas,

Fig. 8. Relative growth of the NaCl sensitive cell lines of *Citrus aurantium* on Na_2SO_4 and $Na_2SO_4+K_2SO_4$ solutions
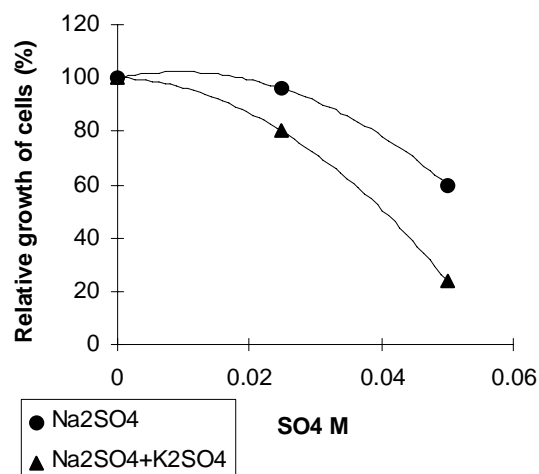
Table VII. Effect of leaf age, drought stress, rootstock and salinity on mean (m=4) predawn osmotic potential (MPa) of 'Valencia' leaves during spring and summer

Season:		Spring				Summer			
Leaf	age/	Young		Mature		Young		Mature	
Drought:									
Rootstock:		Tri	Swt	Tri	Swt	Tri	Swt	Tri	Swt
Cl⁻ (mol m⁻³)									
4		-1.76	-1.84	-2.43	-1.94	-1.93	-1.90	-2.16	-2.27
10		-1.69	-1.72	-2.62	-2.36	---	---	---	---
14		-1.88	-1.78	-2.56	-2.38	---	---	---	---
20		-2.03	-1.81	-2.30	-2.80	-2.40	-2.23	-2.39	-2.47
L.S.D		0.10	0.11	0.31	0.24	0.21	0.26	0.21	0.22

Source: Syvertsen *et al.* (1988)

1993). However, Na^+ and Cl⁻ exclusion capacities in some citrus rootstocks could be lost when salt solutions having osmotic potentials of -0.20 MPa and higher (Zekri, 1993a).

Nieves *et al.* (1991) found that no accumulation of chloride or sodium was detected in leaves of trees budded on sour orange and Cleopatra Mandarin rootstocks. However, symptoms of chloride toxicity were observed in leaves from macrophylla trees (Nieves *et al.,* 1990). Several studies have ranked the rootstocks in the order of their reactive element concentrations. Nieves *et al.* (1990) found that Cleopatra mandarin rootstock is a good excluder, and the more effective restriction of Cl⁻ to leaves was in the combination sour orange/Sanguine orange/'Verna' lemon. Macrophylla is considered as a non-excluder to chloride.

Behboudian *et al.* (1986) reported that Cl⁻ accumulation in shoots was root dependent and Na^+ accumulation was more scion dependent. The chloride exclusion ability of the rootstock is associated with yield reduction. Cerda *et al.* (1990) found that yield decrease of trees on sour orange, comparing the highest salinity treatment to the control, was 37%; whereas, on the other rootstocks lemon tree yield decreased by 46% and 56% in Cleopatra and macrophylla, respectively. However; fruit yield decline in trees on sour orange and Cleopatra

mandarin rootstocks was mainly associated to an osmotic effect rather than specific toxicity.

All scion-rootstocks combinations showed similar uptake of Na^+ by the whole plant (Banuls *et al.,* 1990). However, the distribution of Na^+ between different organs appears to differ for each combination. Plants grafted on Cleopatra mandarin (good Chloride excluder) accumulated more Na^+ in leaves than plants grafted on Troyer citrange. In contrast, plant, grafted on Troyer citrange accumulated more Na^+ in rootstock than plants grafted on Cleopatra mandarin. So, the good chloride excluder rootstock, exhibits more Na^+ accumulation in leaves of plants grafted on it, which appears to be more salt-tolerant rootstock.

The controversy in the literature in explanation about the growth reduction at increasing salinity levels is present. Banuls *et al.* (1990) found that this reduction is more scion dependent than Cl^- or Na^+ accumulation in leaves. Behboudian *et al.* (1986) reported that 'Valencia' orange, 'Taylor' lemon and 'Elledale' tangor scions contained similar concentrations of Cl^- in leaf tissues after salt treatment, concluding that major influence of Cl^- accumulation is exerted by rootstock rather than scion. On the other hand, Banuls *et al.* (1990), and Banuls and Primo-Millo (1995) showed a marked influence of the rootstock in accumulation of Cl^- in leaves but of the Scion grafted to Cleopatra mandarin, Clementine (Scion grafted on CM) had a lower concentration of Cl^- than 'Navel' (when grafted on CM), demonstrating scion-rootstock combinations. This effect might be explicable by the reduced ability to transport Cl^- from rootstock to scion observed in combination Clementine / Cleopatra mandarin. However, Cl^- accumulation alone does not appear to be an adequate criterion of salt tolerance (Syvertsen *et al.,* 1988).

In general, the decreasing order of salinity tolerance is: grapefruit lime = Cleopatra mandarin > Sour orange > Sweet orange = Swingle citrumelo > Rough lemon > Poncirus trifoliate (Boman, 1993; Zekri, 1993b).

Thus a rootstocks ranking of Cl^- tolerance generally reflects its water usage. For example, rough lemon and *Poncirus trifoliata* tend to transpire more water (Syvertsen *et al.,* 1988) than Cleopatra mandarin and sour orange. Salt-Chloride tolerant rootstocks tend to produce trees that grow more slowly or that use less water than trees on many salt-sensitive rootstocks.

Physiological Effects

Water relations. Osmotic potential generally decreased as leaves matured and responses to salinity were rootstock-dependent (Table VII). Syvertsen *et al.* (1988) evaluated 'Valencia' orange trees on either *Poncirus trifoliata* or sweet orange rootstocks. The trees have been irrigated with a saline water average 4 mol m^{-3} Chloride or with addition salinity levels to produce 10, 14, and 20 mol m^{-3} Cl^-. Chloride concentration in leaves of trees on Trifoliata was significantly higher than those on sweet orange rootstock. Foliar Na^+ and Cl^- concentrations increased and K concentrations decreased as leaves aged, especially under

irrigation with 20 mol m^3 Cl^- (Alva & Syvertsen 1991; Ben-Hayyim, 1985) (Table VIII).

Leaf osmotic potential was reduced by high salinity, so the reduction in leaf water potential was offset. Leaves of high salinity trees on Trifoliata have lower rates of net gas-exchange than those on Sweet orange. Salinity decreases leaf-water potential and osmotic potentials, foliar accumulation of Na^+ and Cl^- enables leaves to maintain normal or higher pressure. These observations have been made on 1 and 2-year-old orange and grapefruit scions grafted on Trifoliata, Cleopatra mandarin, or sweet orange rootstocks (Lloyd *et al.,* 1990), and on 2-year-old orange, lemon and tangor scions on Cleopatra mandarin rootstocks and orange on rough lemon (Table IX) (Behboudian *et al.,* 1986).

Transpiration. Transpiration rate of both young and old trees are decreased by salinity (Behboudian *et al.,* 1986). The results of Syvertsen and Yelenosky (1988) on 1-year-old 'Pineapple' sweet oranges 'Cleopatra' mandarin, and Trifoliate orange seedlings showed that NaCl stress greatly reduced both transpiration and hydraulic conductivity of the roots (Syvertsen & Graham, 1985; Zekri, 1991a) (Fig. 9).

Zekri and Parsons (1989) found that hydraulic conductivity of the roots decreased by NaCl at -0.10 MPa (19 to 30% in sour orange and Cleopatra mandarin and 78 and 85% in trifoliate orange and 'Milam' lemon). Conductivity reduced more at -0.20 and -0.35 MPa , but not proportionally as much as -0.10 MPa. They attributed this reduction in hydraulic conductivity of roots to root suberization or a decrease in membrane permeability. Thus, salt-stressed roots may have more suberized area per unit root length than non-stressed.

Photosynthesis and stomatal conductance. Despite turgor maintenance, both CO_2 assimilation and stomatal conductance were reduced by salinity. The extent of salt-induced reductions in stomatal conductance and photosynthesis appear to be influenced by both scion and rootstock. Foliar CO_2 assimilation in 'Marsh' grapefruit was found to be more sensitive to salinity than in either Valencia or 'Washington Navel' orange scions (Lloyd *et al.,* 1990). They attributed the effects mainly to Na^+, but Cl^- effects could not be ruled out. Zekri and Parsons (1990b) found similar results on sour orange seedlings. Behboudian *et al.* (1986) also found that Na^+ was more closely correlated with salt-induced reductions in photosynthesis than was Cl^-.

Clearly, the factors responsible for the different effects of salinity on photosynthesis in citrus are complex. Plant response varies with season, tree and leaf age, and various soil and environmental conditions (Syvertsen *et al.,* 1988). The mechanism of the effect of salt stress on gas exchange remains unknown. Lloyd *et al.* (1990) found that stomatal conductance and CO_2 assimilation per unit leaf area were reduced similarly by salinity. They suggested three possible causes, (i) The closure of stomata by salinity decreases mesophyll capacity for CO_2 assimilation, (ii) Salt stress

reduces chloroplast capacity to fix CO_2 which produces a feedback signal to close the stomata, and (iii) Salt stress impairs chloroplast metabolism and guard cell function simultaneously and independently. Garcia-Legaz *et al.* (1993) found that the assimilation rate and stomatal conductance in leaves of three lemon varieties were significantly reduced by salinity, irrespective of the rootstock. The total leaf chlorophyll per unit area decreased in response to high salinity (Behboudian *et al.,* 1986; Syvertsen *et al.,* 1988; Zekri, 1991a; Garcia-Legaz *et al.,* 1993). Carcia-Legaz *et al.* (1993) found that the slope of linear regression between the stomatal conductance (SC) and transpiration (TR) expressed by the equation:

TR = 0.175 SC - 0.76

And the linear regression between stomatal conductance and assimilation of CO2 (AR):

AR = 5.36 SC - 2.28

The higher value of the latter indicate that the closure of stomata affect net gas exchange more than transpiration. Lloyd *et al.* (1990) found that CO_2 assimilation reduced to greater extent for scions on Cleopatra mandarin than equivalent foliage on Trifoliata stocks.

The shoot: root ratio is also affected by salinity. The shoot: root ratio of 'Valencia' orange and 'March' grape fruit were higher when scions were budded on Cleopatra mandarin than on Trifoliata. Although Trifoliata had higher photosynthesis than Cleopatra mandarin, this did not cause higher shoot: root ratio. This is because a larger root biomass in trees on Trifoliata may have contributed towards this effect of rootstock on scion-leaf photosynthesis. Zekri (1993a) found that shoot: root ratio was reduced under salinity stress in Swingle citromelo and Cleopatra mandarin, while increased in Carrizo citrange, Volkamer lemon, Troyer citrange and Rough lemon.

Physical characteristics. Yield reduction by salinity was not caused by changes in physical conditions or juice content. However, juice quality was affected by both salinity and rootstock. The total soluble sugars (TSS) and

Table VIII. Effect of leaf age, drought stress, rootstock and average salinity (Cl-) concentration in the irrigation water of mean (n=4) chloride (Cl-), sodium (Na+) and potassium (K+) ion content (mmol/L) of 2-month-old (young) or 4 to 6-month-old (mature) Valencia leaves on P. trifoliata (Tri) or sweet orange (Swt) rootstocks during spring or summer

Ion:												
							Spring					
	Cl⁻				Na⁺				K⁺			
Leaf age:	Young		Mature		Young		Mature		Young		Mature	
Rootstock:	Tri	Swt	Tri	Swt	Tri	Swt	Tri	Swt	Tri	Swt	Tri	Swt
Cl⁻ (mol m⁻³)												
4	33	3	151	20	5	2	9	14	159	141	128	200
10	65	39	372	61	2	2	8	15	115	127	74	139
14	43	39	212	85	2	2	9	12	136	122	72	90
20	85	77	396	196	2	5	39	9	195	155	67	63
L.S.D (P 0.05)	< 24	25	85	53	2	3	15	7	70	40	28	51

Ion:												
							Summer (Mature)					
	Cl⁻				Na⁺				K⁺			
Drought:	Well-watered		Droughted		Well-watered		Droughted		Well-watered		Droughted	
Rootstock:	Tri	Swt	Tri	Swt	Tri	Swt	Tri	Swt	Tri	Swt	Tri	Swt
Cl⁻ (mol m⁻³)												
4	92	15	85	17	4	4	4	10	205	214	183	208
20	231	197	157	107	82	26	61	59	148	93	130	110
L.S.D (P 0.05)	< 82	47	60	43	9	16	17	36	68	51	42	60

Source: Syvertsen *et al.,* (1988)

Table IX. Water,. osmotic and turgor potentials (MPa) in citrus leaves of some scion-rootstock combinations treated with 0 (control) or 75 mM Cl⁻ solution for 75 days. Values are averages of three replicates. Asterisks denote significant differences from the corresponding control values at *P < 0.05 and **P < 0.01

Combination	Water potential		Osmotic potential		Turgor potential	
	Control	Salt-treated	Control	Salt-treated	Control	Salt-treated
E/CM	-1.45	-1.61	-2.35	-3.37*	0.9	1.76*
T/CM	-1.34	-1.62*	-2.10	-2.75**	0.76	1.13
V/CM	-1.36	-1.75	-2.31	-3.08*	0.95	1.33
V/RL	-1.28	-1.44	-2.35	-3.10*	1.07	1.66*
RL	-1.22	-1.55	-2.03	-2.69**	0.81	1.14

Source: Behboudian *et al.,*(1986); E, T, V: are Ellendale tangor, Taylor Lemon, and 'Valencia' orange scions, respectively; CM, RL: are Cleopatra mandarin and Rough Lemon rootstocks, respectively

acidity are the most important components of juice quality. Nieves *et al.* (1991) found that the 'Verna' lemon juice on sour orange and Cleopatra mandarin rootstocks (salt-tolerant rootstocks; threshold values 1.53 and 2.08 dS m^{-1}, respectively (Cerda *et al.,* 1990)) were superior to macrophylla because their fruits were highly satisfactory in both total soluble sugars (TSS) and acidity. The effect of salinity on peel thickness varied with rootstock. The thickness of the peel increased with salinity. Lemons from macrophylla rootstock had the thickest peel (Nieves *et al.,* 1991).

Environmental interactions. Climatic conditions influence plant response to salinity more than any other factor. Salt stress can be tolerated by most crops if the weather is cool and humid than if it is hot and dry. Storey (1995) found that the plants in the high humidity cabinet did not develop any symptoms of salt-induced leaf necrosis, except for one sand-grown salt-sensitive Etrong citron plant. This because rates of transpiration in low humidity cabinet was higher (2.1 μg/s/m^2) than in the high humidity cabinet (0.55 μg/s/m^2). Syvertsen and Yelenosky (1988) suggest that moderate salinity increase cold tolerance by reducing water loss and physiological activity. Soil fertility interacts with citrus response to salinity. If the citrus crops were grown on low fertility soils, they may seem more salt tolerant than those grown with adequate fertility. Proper fertilization will increase yields weather the soil is saline or not, but proportionately more if it is non saline (Maas, 1993).

The results of Alva and Syvertsen (1991) indicate the importance of soil organic matter and Ca content in determining nutritional characteristics of soil irrigated with salinized water. The presence of shallow water table is a critical factor because it affects root growth and salt distribution. Blacker and MacDonald found that accumulative new roots in saline soil were less than that of non-saline. Salinity reduced number of new roots produced each weak by Troyer citrange seedlings (Fig. 10). Salt levels varied with the depth of soil profile, levels were highest in the top 8 cm of soil (16.2 dS m^{-1}) and decreased with depth to 4.4 dS m^{-1} at 43 cm, this was attributed to the high salt content of the water table.

Soil water and salt distribution. In citrus areas where summers rains are dominate, irrigation with saline water is more of short-term problem because salts are frequently diluted and leached during the growing season (Syvertsen *et al.*, 1989). Salinity varies with soil depth. In well-drained soil, salt concentration may range from that of the irrigation water at the top of the rootzone, to concentrations several-fold greater at the bottom. Consequently, trees must respond to salt concentration that differ several-fold within rootzone. Furthermore, root distribution, which differs among rootstocks, must respond to changes in soil nutrients and water, as well as to variable salt concentrations (Alva & Syvertsen, 1991). Cerda *et al.* (1990) assumed that a quasi-steady-state has been reached. The EC$_e$ of soil and chloride distribution was relatively stable throughout the profile, in

two salinity levels, on this assumption about 90% of the uptake occur above a soil depth 0.6 - 09 m for all treatment. The weighted salinity and chloride concentration for the entire root zone were calculated.

Therefore, the tolerance of citrus plants to salt should be related to salt concentration that are integrated over time and weighted by depth in relation to proportion of water absorbed.

Irrigation and Salinity Management

Leaching requirement. Successful irrigation management to control salinity requires adequate leaching, e.g. water application must sufficiently exceed the crops water requirement to remove excess salts from the rootzone. Ideally, leaching should remove enough salt to prevent concentrations from exceeding the crops tolerance threshold. However, little information is available on the leaching requirement for citrus (Maas, 1993).

Syvertsen *et al.* (1989) reported that citrus grown on well-drained, permeable soils in Florida have survived short - term irrigation with 4.6 dS m^{-1} (300 ppm) water with only moderate injury symptoms. Cerda *et al.* (1990) used chloride values to calculate the leaching fractions (Cl^-_w/ Cl$^-_{dw}$). These leaching fractions ranging from 0.18 (S$_1$ = 2.54 mol m^{-3} based on the corresponding chloride concentrations of the irrigation water diluted by rainfall) to 0.44 (S4 = 26.99 mol m^{-3} after dilution).

The consumptive water use by 'Valencia' orange reduced with increased salinity. This suggested that the leaching fraction might be self adjust, i.e., as evapotranspiration decreases, the leaching fraction would increase if the same amount of water is applied (Maas, 1993).

Irrigation method. The response of citrus crops to soil and water salinity also depends on the method of irrigation and its frequency. Several irrigation methods (gravity, sprinkler, and drip) are used on citrus. The differences in water distribution by these systems directly affect the distribution of soil salinity in the rootzone. Crops irrigated with sprinkler irrigation are subject to injury not only from salts in the soil but also from salts absorbed directly through wetted leaf surfaces (Mass, 1993).

Sprinkled lemon and orange leaves directly absorb ions and accumulate more Na$^+$ and Cl$^-$. However, foliar absorption is highly dependent on the ion concentration in the water film on the leaves, which is increased by evaporation between wetting cycles and during periods of high evaporative demand. Management practices suggested to minimize foliar injury from sprinkling include, (i) Irrigating below the canopy to eliminate or reduce wetting of the foliage, (ii) Irrigating at night or at times of low evaporative demand, (iii) Irrigating infrequently with heavy applications of water rather than with frequent light applications, and (iv) Avoiding intermittent wetting by slow rotations of sprinklers that result in repeated wetting and drying cycles (Syvertsen *et al.,* 1989).

Irrigation with high-sulfate water. Irrigation with high

chloride water has been well investigated (Cole, 1985; Behboudian *et al.,* 1986; Ben-Hayyim *et al.,* 1987; El - Boray, 1988; Syvertsen & Yelenosky, 1988; Ben-Hayyim *et al.,* 1989; Banuls *et al.,* 1990; Lloyd *et al.,* 1990; Nieves *et al.,* 1990; Zekri & Parsons, 1990a; Cerda *et al.,* 1990: Nieves *et al.,* 1991; Dasberg *et al.,* 1991; Alva & Syvertsen, 1991; Banuls & Primo-Millo, 1992; Boman, 1993; Zekri, 1993a; Banuls & Primo-Millo, 1995; Cerda *et al.,* 1995; Storey, 1995). However, very little is known about the effects of the high-sulfate waters on crops sensitive to salinity.

Metochis (1989) studied the effect of irrigation with different amounts of high-sulfate water on the growth and yield of 'Marsh' grapefruit trees. Grapefruit is sensitive to salinity, yield reduction of 1.45% for each 1 meq L^{-1} increase in chloride concentration of the soil saturated extract above a threshold value of 4.5 meq L^{-1} was reported by Metochis (1989). The soil was a deep-fine-textured (Clay 53% silt 25%, sand 22%), calcareous (25% CaCO$_3$) alluvium, low in organic matter (1%). The water used for irrigation was saturated with gypsum (CaSO$_4$ 2H$_2$O) had an EC$_{iw}$ = 4.1 ds /m and contained in me L^{-1}.

Ca^{2+}	Mg^{2+}	Na$^+$	K$^+$	Cl$^-$	HCO$^-_3$	SO$^-_4$
29.5	8.5	4.1	0.2	3.3	3.6	37.0

The results indicate an increase in soil profile salinity due to accumulation of salts of both low (Ca^{2+}, SO$^-_4$) and high (Na$^+$, Cl$^-$) solubility. Irrigation with high sulfate water resulted in an inevitable salinity in the soil profile, governed by the solubility of gypsum. Gypsum precipitation/ dissolution created a low and constant salinity in the soil profile, which was not leached by winter rainfall or by application of water in excess of the irrigation requirement. On the other hand, Cl$^-$ salts had been leached by winter rainfall.

Because of the low concentration of highly soluble salts in the irrigation water, no significant salinity increase occurred in the main rootzone. The lowest amount of water applied resulted in water-stress and slower fruit growth, consequently less fruit was picked. Therefore, irrigation with 600-700 mm of water over the irrigation season proved sufficient for maximum yield using high - sulfate water.

Metochis (1989) concluded that the use of high-sulfate water for irrigation of grapefruit, although high in salinity 4.1 dS m^{-1}, seems not to present a serious problem. The tree grows less, but the volume of the yield per tree remained similar to that of trees irrigated with low salinity water. The constant non-leachable salinity created in the soil profile is rather low, as accumulation of Ca^{2+} and SO$^-_4$ above gypsum solubility product is prevented by its precipitation.

Selecting salt-tolerance citrus rootstocks. While Citrus trees are considered to be salt-sensitive glycophytes, they exhibit a wide variation for chloride-ion exclusion with species and cultivars (Sykes, 1992) this variation has stimulated breeding programs aimed at producing new salt-tolerant rootstocks (Spiegel-Roy & Ben-Hayyim, 1985).

High leaf Cl$^-$-ion concentration in citrus scions can lead to physiological disturbances and eventually visible leaf damage. High leaf Na$^+$-ion concentrations also have detrimental effects on photosynthesis and transpiration (Behboudian *et al.,* 1986). Ability for Cl$^-$-ion exclusion by citrus hybrids from crosses, involving Cl$^-$-ion excluding parents varies widely, suggesting that it is a polygenic trait. Also, the ability to restrict Na$^+$-ions accumulation in shoots is a polygenic trait (Spiegel-Roy & Ben-Hayyim, 1985; Sykes, 1992). However, the good Cl$^-$-ion excluder is a poor Na$^+$-ion excluder (for example Cleopatra mandarin). This suggests that the ability to exclude these ions is due to two different mechanisms, although further experiments are needed to show this definitively: (i) As far as Cl$^-$-ion exclusion criteria is concerned, the disadvantages of using Cl$^-$ exclusion as the selection criteria include the limited ability of citrus to exclude sodium and chloride ions; the possibility that Na$^+$ may be important; and an uncertain understanding of the significance of Na$^+$ and Cl$^-$ ions in growth, and (ii) In addition to the former selection criteria, another selection criterion was used by Gallasch and Dalton (1989). That is vigor as measured by differences in plant height, leaf expansion and abscission. They conclude that Cl$^-$ exclusion criteria should not be the only indicator of salt tolerance for all citrus rootstocks. Chloride levels may be related to growth for some rootstocks, but no generalization of such relationship can be made.

Several investigators have assumed that plant to grow and survive under stress altered gene expression, which is exhibited in gene products (e.g. proteins) (Ben-Hayyim, 1989; Rabe, 1990). Anaerobic stress have certain induced proteins been assigned specific function in known metabolic pathway. In all the stresses, proteins have been identified by their physio-chemical parameters e.g. molecular weight and PI. Several reports described salt-induced changes in various proteins. Both short-term and long-term changes have been reported for several salt-affected cells or plants. Ben-Hayyim *et al.* (1989) reported that when electrophoresis of proteins from labeled in vivo was investigated they exhibited (i) 25 kDa polypeptide band was more intense in salt-tolerant cells, in the presence and absence of salt, than salt-sensitive, and (ii) a 32.5 kDa polypeptide band was found in salt-sensitive cell grown in the presence or absence of NaCl. This band was almost absent in the salt-tolerant cells grown in the absence of NaCl.

The above mentioned proteins are not shock proteins. Practically, absent in non-adapted cells. Therefore, the enhanced synthesis of citrus protein in NaCl-tolerant cells was not dependent on the presence of salt in the growth medium. Thus it is a constitutive property, associated with the tolerance to salt acquired by these cells. These variations in mechanisms and proteins involved in salt-tolerance are due to (i) The origin of the cells, (ii) The length of exposure to salt, (iii) NaCl concentration during selection, and (iv) The polygenic nature of salt-tolerance.

In citrus there are many proteins that disappear upon

adaptation to salt. The degree of a change in the level of a given protein does not necessarily indicate its importance in adaptation. The ultimate proof that a protein is involved in conferring salt-tolerance would require the isolation of the relevant gene, its transfer into a salt-sensitive plant and the regeneration of a salt-tolerant variant. This is yet to be done. Rabe (1990) concluded that the lack of feed back inhibition on nitrogen uptake and reduction during periods of reduced growth/ reduced protein synthesis causes $NH_3\text{-}NH_4^+$ accumulation and preferential synthesis of specific amino-containing compounds.

On the other hand, Libal-Weksler *et al.* (1994) found that (L-5) Shamouti salt-sensitive cells had 2-3 fold more starch than tolerant one when grown under control medium, 5 fold more starch than tolerant when grown in presence of 0.1 M NaCl in the medium. These results suggest that adaptation to salt in citrus is characterized by reduced starch biosynthesis, leading to lower starch accumulation as compared to salt-sensitive callus.

The role of salinity in disease. Salinity adversely affects most rootstocks, when ECe is about 2.5-3.0 dS m^{-1}. Another serious problem in most citrus growing areas is Phytophthora gummosis and root rot, caused primarily by Phytophathora parasitica (Blaker & MacDonald, 1986)

The root rot phase of the disease evidenced by decay of small fibrous roots result in general decline and die back of leaf canopy. In areas where soil salinity is a serious problem, phytophthora root rot of citrus was observed to be usually severe. Salinity stress can increase phytophthora root rot severity. Resistance has been attributed partly to rootstock vigor and the capacity to rapidly replace damaged roots. A positive relationship ($r^2 = 0.62 - 0.88$) was found between the ECe of core samples and the percentage of root length rotted by *P. parasitica.*

Oct. 1982 :	y = 2.45x +2.08	r^2= 0.62
July 1983 :	y = 4.11x +0.77	r^2= 0.76
Oct. 1983 :	y = 2.14+3.58	r^2= 0.88

This observed relationship was when sweet orange seedlings were exposed to high salinity, the severity of infection by *P. parasitica* increased. On the other hand, Troyer citrange seedlings appeared unaffected by salinity treatments. The Phytophthora severity in citrus can be influenced by high salinity in several ways: (i) The damage caused by irrigation with salinized water has varied from severe leaf burn to complete defoliation, which Cl$^-$ toxicity consists of necrotic areas on leaf margins, the most common visible salt injury symptoms (Blaker & MacDonald, 1986), (ii) Toxicity symptoms usually appear when leaf Cl$^-$ level reach about 1% of leaf dry weight, while Na$^+$ level reach 0.1-0.25% of leaf dry weight. High Na$^+$ in leaves can be physiologically more detrimental than excess Cl$^-$ (Syvertsen *et al.,* 1988).

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