INFLUENCE OF SALINITY ON CITRUS: A REVIEW PAPER

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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. Primarily 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 prevailing 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 or salt stress partially inhibits the growth of most plants.

The four reasons that are usually introduced as solely responsible for reduction of plant growth under salt-stressed conditions are: osmotic stress caused by lowering the availability of external water, specific ion toxicity effects caused by metabolic processes in the cell, nutritional imbalance caused by these ion-toxicity effects, and combination of any two of the above-mentioned factors.

Citrus is salt-sensitive [3, 12, 25, 26, 42, 48]. Its response to salinity depends on several factors: These include rootstock - scion combinations, irrigation system, soil type and climate. 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.

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 present 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 as 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 review 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 [12].

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 [25].

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 [13, 17].

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.

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 [13, 17].

The fruit yields decreased by salinity, however; the average fruit yield over the six-year experimental period did not show any significant effects of treatments [13]. The average EC_e values for the C_1, Cl_2 and Cl_3 treatments were 2.0, 2.8 and 3.4 ds/m, 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 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. The growth of citrus species and their fruit yield generally reduced at soil electrical conductivities (ECe) above 1.4 ds/m [26].

Salinity, not only reduced growth and yield due to the osmotic potential effect, but for the same reasoning salinity delayed and depressed emergence, reduced shoot and root biomasses [49]. However, the beneficial effect of (Ca) addition to the saline irrigation water is valid during emergence. The addition of 5 mol/m^3 $CaSO_4$ 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 [48].

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 Ca 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 [13].

Four salinity levels treatments (range 2 to 5 meq/L Cl^-) when applied to mature orange trees grown on Rough lemon rootstock [15] resulted in soil salinities of 0.9 to 1.5 ds/m. Although these salinities were less than threshold, yield decrement of about 20% above a threshold level of about 4.3 meq/L. These yield decrements were due to chloride toxicity rather than osmotic stress, for osmotic effect soil salinity needs to exceed the threshold value (Figure 1).

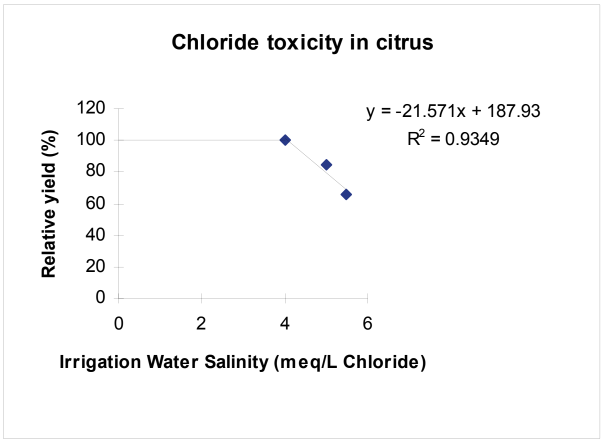

Figure 1. Effect of irrigation water salinity on yield of Washington Navel Oranges on Rough Lemon rootstock

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 $CaCl_2$ in the median.

The replacement of NaCl by KCl had a more pronounced inhibitory effect [8]. 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 2).

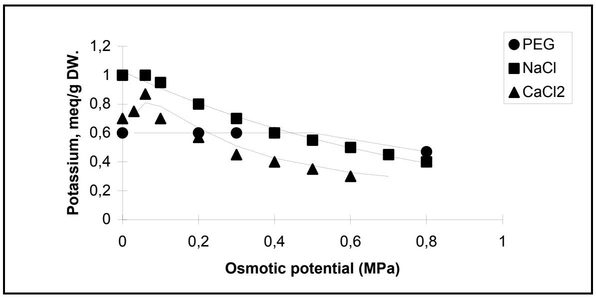

Figure 2. Effect of increasing external PEG. NaCl and CaCl2 concentrations on internal K concentration in salt-tolerant cells.

A reduction in canopy volumes of 'Ruby Red' grapefruit budded on four rootstocks (Sour orange (SO), Carrizo citrange (CA), Cleopatra mandarin (CL), or Swingle citrumelo (SW)) was reported [12]. Irrigation water had electrical conductivities 0.7, 2.3, 3.9, or 5.5 ds/m. The reduction in canopy volume was about 7% for each 1 ds/m increase in irrigation water salinity level above the base level of 0.7 ds/m.

The relative yield reduction of 1.4% for each 1 meq/L increase in Cl concentration of the soil solution extract, above a threshold value of 4.5 meq/L is observed [43, 44].

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 2.

Toxicity symptoms usually appear when leaf CL levels reach about 1% of leaf dry weight. Based on reduction in yield, CL leaf concentration as low as 0.2% can be considered excessive. Toxicity levels appear when leaf Na level reach 0.10- 0.25% of leaf dry weight (linear relationship with salinity $Y= 0.0316 + 0.0181(EC_{iw})$). Because the high Na in leaves can be physiologically more determinable than excess Cl [37].

Leaf Na concentration of grapefruit trees on all rootstocks had a linear relationship ($Y = 0.2409 + 0.1272 (EC_{iw})$) as shown in Fig. 3. 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 salinity level [12].

Table 1. Mean change in trunk cross- sectional area and December 1989 canopy volume by water salinity for each rootstock.

		Rootstock				
Parameter	EC_{iw} (ds/m)	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 [12] Boman, 1993

Table 2. 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: [12] Boman, 1993

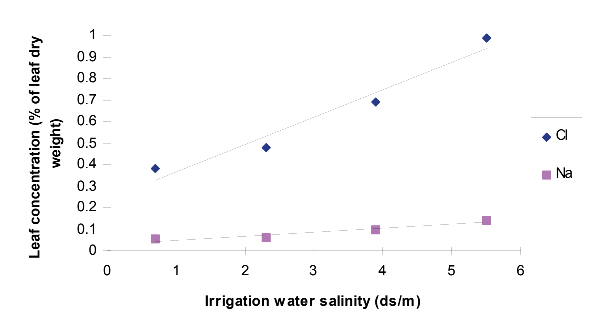

Figure 3. Leaf concentration (% of total dry weight) of Cl and Na in grapefruit trees at different irrigation water salinities.

Although sodium accumulation in leaves of sour orange increased when salinity level increased (370-6000 mg/l), but no results were reported about either the chloride concentration in leaves or about the attributable reason for Na accumulation in the leaves of sour orange seedlings [18].

- NUTRITIONAL IMBALANCE

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 concentration among studies have led to some confusion on the relative importance of Na, as Na toxicity is usually only a problem when Ca concentrations are relatively low [3, 26].

However, few studies have tried to elucidate the mechanism of reduced NO_3 uptake with high Chloride concentration at the whole plant level. N accumulation in 'Navel' orange scion on CM and Troyer citrange was negatively correlated with Cl accumulation during salinity stress [3]. 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.

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 and 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

Table 3: 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: [43] Zekri and Parsons, 1990b.

depth [40, 1].

N- concentrations in leaves and fibrous roots of grafted scions on Troyer citrange rootstock decreased with increasing NaCl in the irrigation solution. However, when these scions had lower foliar Cl concentrations on the relatively more salt-tolerant CM, N concentration did not decrease. The reduction in (N) concentration in leaves and roots was closely related to the accumulation of Cl in tissues. Thus, highly significant negative correlation between N and Phosphor (P) concentrations in the leaves of two citrus cultivars was reported [45, 46].

(N) uptake in the four-week salinity was reduced [21], 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. It was concluded that increasing salinity level would not reduce N and Ca levels in the leaves [47].

In the presence of adequate concentration of Ca, plants exclude Na and withstand the effects of relatively high NaCl concentration.

The beneficial effect of Ca depend on the anion associated with the Ca. 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 and the sensitivity of citrus to Cl, since, none of them was found to overcome the determinal effects of NaCl by decreasing the Na and Cl concentrations in citrus leaves [43, 50].

Table 3 shows the beneficial effect of Ca 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 [43].

Thus, 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 and Mg relative to NaCl alone.

However, Replacement of Na Salts, by K- Salt markedly increased the levels of K^+ with a concomitant significant decrease of growth (Fig 4) [8].

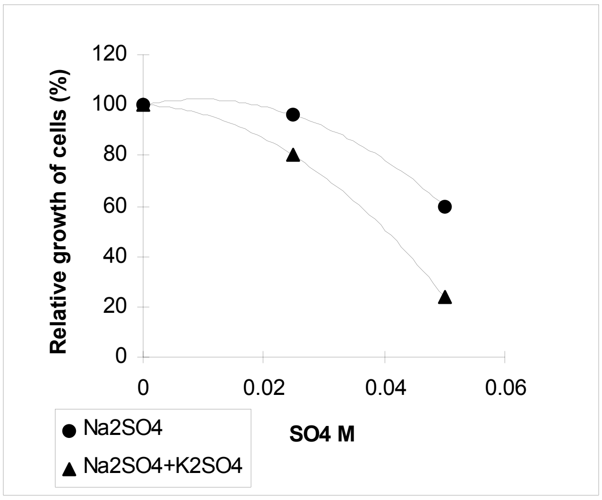

Figure 4. Relative growth of the NaCl sensitive cell lines of Citrus aurantium on Na_2SO_4 and Na_2SO_4+K_2SO_4 solutions.

It was reported that the 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 [8].

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 [6]. However, K concentration reduced 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) [47].

Increasing salinity worsened nutritional imbalances, However this effect was rootstock dependent. It was found that leaves and roots of four scion-rootstock combinations showed no increase in Na and a decrease in K, Ca and Mg concentrations during salt treatment [3, 5, 6, 1, 36].

The decrease in Mg concentration in leaves of salt affected trees could be attributed to the low Mg concentration in the exchange complex. salinity not only increased soil EC_e, Na, Cl and Ca, but also increased P concentration and decreased Mg [1]. Increasing Ca (by addition of Ca as gypsum $CaSO_4$) has been shown to decrease Mg concentration, primarily due to displacement of Mg from the soil complex.

SCION-ROOTSTOCK INTERACTIONS

Studies have indicated some differences in salt tolerance among citrus rootstocks, based on visual leaf burn symptoms and leaf Cl content [3, 12, 26, 25, 42, 48].

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 [26]. 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 [48].

Several studies have ranked the rootstocks in the order of their reactive element concentrations. 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 [29, 6, 13].

The controversy in the literature in explanation about the growth reduction at increasing salinity levels is present [3, 5]. 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 [36].

In general the decreasing order of salinity tolerance is: grapefruit lime = Cleopatra mandarin > Sour orange > Sweet orange = Swingle citrumelo > Rough lemon > Poncirus trifoliate [12, 48].

Significant effect of salinity and rootstock on growth and fruit yield were found [13], the growth and yields of 'Verna' lemon trees.

PHYSIOLOGICAL EFFECTS

Osmotic potential generally decreased as leaves matured and responses to salinity were rootstock-dependent (Table 4).

Chloride concentration in leaves of trees on Trifoliata were 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 [1, 7] (Table 5).

Table 4. 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/ Drought:	Young		Mature		Young		Mature	
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.

Table 5. 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.

		Spring											
Ion:		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
		Summer (Mature)											
Ion:		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.

- Irrigation with High-SULFATE Water

Irrigation with high chloride water has been well investigated [1, 3, 4, 5, 6, 7, 10, 12, 13, 16, 18, 24, 29, 32, 36, 48, 42, 15). However, very little is known about the effects of the high-sulfate waters on crops sensitive to salinity.

Grapefruit is sensitive to salinity, yield reduction of 1.45% for each 1 meq/l increase in chloride concentration of the soil saturated extract above a threshold value of 4.5 meq/L was reported by [27].

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.

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