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EFFECT OF SALINITY ON CITRUS

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ABSTRACT: *Citrus is a salt sensitive crop. Salinity significantly limits citrus production in many areas worldwide. Saline irrigation water reduces the yields of citrus. Fruit yields decrease about 13 % for each 1.0 dS* m^{-1} *increase in electrical conductivity of the saturated-soil extract* (EC_e) *once soil salinity exceeds a threshold* (EC_e) *of 1.4 dS* m^{-1}. *Accumulation of excess* Cl^- *and* Na^+ *can cause specific ion toxicities but this problem can be minimized by selecting rootstocks. The objective of this study is summarized the recent literature with regard to respond of citrus to salinity. About eighty papers were reviewed from 1950 to-date. Results of the literature review were summarized in three tables.*

Keywords: Citrus spp.*, salinity, salt stress, morphological effects, chemical effects, rootstock, scion*

TUZLULUĞUN TURUNÇGİLLERE ETKİSİ

ÖZ: *Turunçgiller tuza karşı hassas bitkilerdir. Dünyanın birçok bölgesinde tuzluluk turunçgil üretimini önemli şekilde sınırlandırır. Tuzlu sulama suyu turuçgillerde verimi düşürür. Toprak ekstraktı elektriksel geçirgenliğindeki* (EC_e) *her 1,0 dS* m^{-1}*lik artış, turunçgillerde yaklaşık % 13'lük verim düşüşlerine neden olmaktadır. Aşırı* Cl^- *ve* Na^+ *alınımı toksisiteye neden olur, ancak bu sorun uygun anaçların seçimi ile bir miktar azaltılabilir. Bu derlemenin amacı tuzluluğun turunçgiller üzerindeki etkileri ile ilgili kaynakları özetlemektir. 1950'den günümüze kadar yayınlanan yaklaşık 80 literatür özetlenmiştir. Ayrıca sonuçların bir kısmı 3 tabloda da ortaya konulmuştur.*

Anahtar Sözcükler: *Turunçgiller,* ***Citrus spp****., tuzluluk, morfolojik etki, kimyasal etki, anaç, kalem*

INTRODUCTION

Citrus species belong to the subfamily *Aurantioideae* in the family *Rutaceae*. Most of commercial citrus is grown under Mediterranean or summer-rain climates and requires irrigation for maximum production. Soils in these areas may be sufficiently saline to reduce the growth and yields of citrus crops. Increasing salinity of irrigation water in combination with progressive salinization of agricultural soils is inhibiting agricultural productivity in many semi-arid and arid regions of the world. Citrus is a salt sensitive crop (Maas and Hofmann, 1977). Compared to other agronomic and horticultural crop, citrus species are among the most sensitive to soil salinity (Maas, 1990). Tolerance to salinity varies, however, among species and even among varieties or rootstocks within a species. While citrus rootstocks differ in capacity for sodium and chloride ion exclusion, citrus scion species also vary in foliar sensitivity to $NaCl^-$ salinization. These differences usually reflect the plant's capability to prevent or retard Cl^- accumulation in the tops.

Trees growth and yield in general may be affected by the Na^+ status of soils as well as by salinity. The effects of Na^+ can be both direct and indirect. Direct effects are due to the accumulation of toxic levels of Na^+ and are generally limited to woody species (Maas, 1986). Their sensitivity varies considerably because Na^+ uptake varies widely among species and rootstocks. Sodium injury in citrus trees is rather widespread and can occur at Na^+ concentrations as low as 5 mol/m^3 (~ 0.5 dS/m) or when concentrations exceed 7-10 mol/m^3 (0.7-1.0 dS/m in soil extract) (Bernstein, 1981). Even electrical conductivity of soil extract (EC_e) of 0.2 to 0.3 dS/m may cause toxic accumulations of these ions in leaves of citrus (Bernstein, 1975).

Indirect effects include both nutritional imbalance and impairment of soil physical conditions. The nutritional effects of sodium are not simply related to the exchangeable sodium percentage (ESP) of soils, but depend upon the concentrations of sodium, calcium and magnesium in the soil solution. Thus, yield reductions may occur in crops that are not specifically sensitive to sodium owing to the combined effects of nutritional problems and impaired soil physical conditions (Maas, 1986). Environmental and adaptic factors influence citrus salt tolerance. Relative humidity and temperature are important climatic factors. As most crops citrus are more sensitive to salinity under hot and dry conditions than under cooler and wet conditions (Ben-Asher, 1993).

Numerous studies were conducted in the last four decades on the effect of salinity on citrus. This review summarizes some of these studies and is concentrated on the macroscopic aspect of the effect of salinity. This aspect of the study deal with trees organs or the whole plant rather than the microscopic aspects which deals with the molecular, or the cellular aspects of the effect of salinity.

There are factors that affect the response of citrus to salinity. In these factors we included: Rootstock, scions, fertilizers and climatic conditions. On the other hand, there are various of citrus response to salinity physiological parameters that are characteristic to citrus under saline conditions. Among these parameters we included: Morphological, physiological and yield variations.

MORPHOLOGICAL EFFECTS

The vegetative development of citrus trees is closely dependent upon the irrigation regime and irrigation water quality. The vegetative growth of citrus is often reduced by saline soils. Leaf expansion rates are relatively lower under saline conditions than under nonsaline for various plants (Fischer and Hagen, 1965; Rendig and Taylor, 1989). Leaves of citrus grown under saline conditions are commonly thicker and more succulent than those grown under nonsaline conditions (Maas and Hoffman, 1977). Microscopic examination showed that the increase in leaf thickness was due to the development of larger cells in the spongy mesophyll (Zekri and Parsons, 1990 c). The thicker leaves have higher ratio of mesophyll surface area to total leaf surface area (Longsteth and Nobel, 1979). Jennings (1968) and Lloyd and Howie (1989) reported that increased succulence of salinized leaves on orchard citrus trees was correlated with foliar sodium levels, which also support to this investigator.
In general, leaf area is smaller under saline conditions. Lloyd and Howie (1989) reported that despite a high number of vegetative buds on "Washington Navel" orange, leaf area of trees irrigated with 20 mol/m^3 NaCl, was less than that of trees irrigated with nonsaline or low saline water.

Citrus develops a relatively shallow root system compared with some deciduous fruit trees. The maximum depth of rooting in deep, well-drained soils is 1.2 to 1.5 m with the main root system spreading to a depth of 0.6 to 0.9m. However, the roots can be much deeper in well-drained sandy soils. On the other hand, citrus trees can survive in shallow soils, but may develop smaller trees (Shalhevet and Levy, 1990).

Root growth is often less sensitive to salinity than shoot growth, so the root: shoot ratio increases at high salinity conditions. At low salinity, root growth may not decrease at all while shoot growth declines (Ackersan and Youngner, 1975; Dudeck *et al*., 1983). These effects are also clear in the short term (one or two days), before saline ions accumulation in the shoot would have built up to high levels.

The distribution of sour orange roots is affected by soil salinity and increased salinity resulted a 10% reduction in root development in the layer below 0.3 m and increased roots in the upper layers. Relative water uptake in the 0.6 to 0.9 m layer was reduced by 20% as salinity increased EC_e from 2.0 to 5.6 dS/m (Bielorai *et al*., 1978).
Leaf dry weight:leaf area of Cleopatra mandarin and Trifoliata orange rootstocks increased with salinity (EC_e= 4.8-11.7 dS/m) because of decreases in total leaf area: and as a result of total shoot dry weight decreased (Syvertson and Yelenosky, 1988).

20 years old Shamouti orange trees on Palestine sweet lime rootstock, a reduction of the root system occurred when EC of irrigation water 1.8 dS/m done (Bielorai *et al*., 1986; Dasberg *et al*., 1986).

Under saline conditions, both shoot and root dry weights of various citrus rootstocks seedlings were reduced by 16 to 55% due to change of the osmotic pressure of -0.10 and -0.20 MPa (EC_e= ~ 2.8 and 5.6 dS/m) (Zekri and Parsons, 1989). In another study, root and shoot dry weights of sour orange were reduced by 30% when irrigated with 40 mM (EC_e= ~ 4 dS/m) NaCl compared to nonsaline (Zekri and Parsons, 1990). This induced reduction in root and shoot dry weight was significantly inhibited when irrigation solution contained 40 mM NaCl (as above) and 1.5 or 7.5 mM $CaS0_4$. At high salinity (0.12-0.24 MPa, EC_e= ~ 3.3-6.6 dS/m) root number was reduced and a shallower root system, fewer leaves, shorter shoot and fewer roots were observed (Zekri and Parsons, 1990b). At -0.10 MPa (EC_e= ~2.8 dS/m) salinity levels, shoot and root dry weights, stem cross-sectional area, total leaf area and fibrous roots length were reduced by 44-55%. At 50 mol/m3 NaCl salinity treatment, a reduced shoot and root biomasses of seedlings of some citrus rootstocks occurred (Zekri, 1991 and 1993 a). In these studies, shoot and root ratio was lowered at the higher NaCl $^-$ concentrations and vegetative growth was depressed compared to control.

The vegetative development of citrus trees depends also upon rootstocks. Gallasch and Dalton (1989) obtained a significant growth reduction of fifteen rootstocks due to salt treatment (EC_e= 8.7 dS/m). Measurements of vegetative development of seedlings of various rootstocks correlated with the rate of chloride accumulation. Dry weight of Cleopatra mandarin was reduced by 45% as the chloride concentration of the irrigation water increased to 62 mol/m3 (EC_w= 6.2 dS/m), while growth of sour orange was reduced by 62% and that of rough lemon by 74% (Rokba *et al*., 1979). The reduction rate of shoot length of lemon was also effected by various rootstocks under saline conditions (Garcia *et al*., 1983). On the other hand, Goell (1967) could not find any correlation between the vegetative development of Eureka lemon, grafted onto various rootstocks, and chloride concentrations. Lemon grafted onto rough lemon rootstock showed the most enhanced growth despite the highest chloride uptake. While lemon trees, grafted on Cleopatra mandarin rootstock, grew strongly with little chloride accumulation, Eremocitrus (*Eremocitrus glauca* x *Citrus sp.*) showed enhanced chloride uptake and weak growth. Banuls *et al*. (1990) reported that the reduction in relative growth caused by salt treatments (up to 60 mM NaCl) was more scion dependent whereas defoliation was more rootstock dependent.

Effects of salinity may vary with the growth stage of the plant. It is formerly thought that the germination stage is generally more salt sensitive than later growth stages (Bernstein, 1974; Csizinszky, 1996). Yet Zekri (1993a) reported that increasing salt concentration in nutrient solution, seedling of some citrus rootstocks delayed their emerge by three to five days. Final emergence was however reduced by less than 30% in some rootstocks, and by more than 65% in others rootstocks. Seed germination under saline conditions appeared to be completely unrelated to the sensitivity of the seedlings to salinity (Mobayen and Milthorpe, 1977). Furthermore, the most sensitive rootstock (*Poncirus trifoliata*) was least affected by NaCl concentration of 100 mol/m^3 (there was no reduction in final germination), while final germination of Cleopatra mandarin seeds was reduced by 20% and that of Bakraie mandarin (*C. reticulata* Blanco) seeds by 53% (Shalhevet and Levy, 1990).

CHEMICAL EFFECTS

Bielorai *et al.* (1986) found increase in the chloride content in leaves of Shamouti orange, from 1.6 to 3.1 g kg^{-1} when irrigated with up to 13 mol m^{-3} Cl in the irrigation water.

When trees were irrigated with 8.7 dS/m saline water chloride uptake was negatively correlated to nitrogen uptake and positively correlated to calcium uptake (Gallasch and Dalton, 1989). Sodium uptake was negatively correlated with nitrogen, potassium and manganese uptake. The results reported by Zekri (1993a) supported this investigation. He observed that sodium, chloride, nitrogen, phosphorous and potassium contents of shoots of most citrus rootstocks increased, but calcium and magnesium contents decreased when the seedlings were irrigated with 50 mol m^{-3} (5 dS/m) NaCl.

Increasing salinity (40-80 mol m^{-3} or 4-8dS/m NaCl$^-$) resulted in chloride accumulation in sour orange and macrophylla rootstocks differed whereas, at low (0.5 mol m^{-3} NaCl$^-$) and medium salinity (10 or 20 mol m^{-3} NaCl$^-$), there was no difference (Nieves *et al.*,1991a).

Adverse effects of salinity on photosynthetic rates, which were of the observed were associated with decreases in chlorophyll content (Rendig and Taylor, 1989). Chlorophyll contents were markedly reduced by increased salt treatments. At salinity level of -0.10 MPa, leaf chlorophyll content was reduced by 56 % in Sour orange and by 11 % in Cleopatra mandarin when compared to nonsaline level (Zekri, 1991).

Salinity stress may result in accumulation of proline and betaines in citrus leaves. Free proline appeared in leaves Verna and Fino lemon trees that grown under saline conditions (Nieves *et al.*, 1991b). On the other hand, Lloyd *et al.* (1989 and

1990) reported that leaf proline betaine concentrations of Valencia orange, Washington Navel orange, Prior Lisbon lemon and Marsh grapefruit trees budded on Trifoliata orange, Cleopatra mandarin or Troyer citrange was unrelated with salinization.

The concentrations of sugar and citric acid in the citrus juice are important parameters for fruit quality. Besides, the ratio between total soluble solids (TSS) and citric acid are the most important factor in determining fruit quality. Citrus juice quality (TSS and acidity) is affected by salinity (Nieves *et al.*, 1991c). Generally, saline conditions cause an increase TSS and acid concentrations in the citrus juice. Acidity may affected more than TSS and as a result, TSS:Citric acid ratio becomes lower. Levy *et al.* (1979) reported that salinity affected several juice quality parameters of Marsh Seedless grapefruit but did not affect fruit weight or diameter, peel thickness or juice content. TSS, sugar and acid percentages in the juice were all significantly increased in fruit from trees irrigated with 2.0 dS m^{-1} water compared to 1.1 dS m^{-1} water. Bielorai *et al.* (1988) reported that irrigation waters containing up to 450 mg Cl^{-1} caused slight increases in TSS and sucrose contents and the TSS:Acid ratio of the fruit. Francois and Clark (1980) found that increasing salt stress delayed fruit maturation but had little effect on the quality of Valencia oranges grown in sand culture. In addition, chloride uptake and transport into leaves and fruits is generally increased when trees are irrigated with saline water. Levy and Shalhevet (1990) found high correlation between chloride concentrations of fruit juice and leaf when trees were irrigated with different quality waters.

PHYSIOLOGICAL PROPERTIES

Metabolic activities have been associated with salinity levels. In citrus, treatment with saline irrigation water can reduce physiological activity.

There is a clear correlation between photosynthesis, stomatal conductance and salinity. Generally high salinity reduces photosynthesis and stomatal conductance (Downton, 1977; Garcia *et al.*, 1993). Net photosynthesis is strongly affected by NaCl saline conditions and is directly related to reduction in stomatal conductivity as well as low intercellular CO_2 levels (Downton *et al.*, 1985). Rates of CO_2 fixation decreased when levels of chloride in the leaves increased (Lloyd *et al.*, 1989, 1990; Banuls and Primo-Millo, 1992). This decrease in photosynthesis could be largely attributed to increased residual (mesophyll) resistance to CO_2 fixation and stomatal closure and decomposition of leaf chlorophyll pigments (Ruan *et al.*, 1988). Salt stressed leaves contained decreased amounts of sucrose and starch (Howie and Lloyd, 1989; Garcia *et al.*, 1993), but increased levels of reducing sugars.

Citrus exhibited reduction in photosynthesis prior to the appearance of any visible symptoms of salt damage. However photosynthetic activity, like growth, is a turgor dependent process and can often be sustained, despite of salt treatment, if osmotic adjustment is sufficient to offset the reduction in leaf water potential that would normally occur following addition of NaCl to the root medium (Gale, 1975). Etrog citron assimilation of salt stressed seedling declined (Walker *et al.*, 1982). Similarly, Valencia orange, Washington Navel orange and Marsh grapefruit trees that grown under saline conditions occurred reduction in both CO_2 assimilation rates and stomatal conductances were reduced (Lloyd *et al.*, 1987). CO_2 assimilation was greatly reduced at Prior Lisbon lemon trees (Lloyd *et al.*, 1989; Garcia *et al.*, 1993) and Verna and Eureka lemon trees on Sour orange rootstock at 50 mol m^{-3} NaCl salinity (Garcia *et al.*, 1993). Stomatal conductances of Sour orange and Cleopatra mandarin seedlings were significantly reduced by various salinity levels (Zekri and Parsons, 1990b; Zekri, 1991).

Like photosynthesis, transpiration and evapotranspiration diminish by salinity. Transpiration rate of Sweet orange, Cleopatra mandarin and Trifoliata orange rootstocks decreased when irrigated with different saline (0, 15, 30 and 60 mM NaCl) water (Syvertsen and Yelenosky, 1988). At 50 mol m^{-3} NaCl salinity and at -0.10, -0.20 and -0.35 MPa saline levels, evapotranspiration of Sour orange and Cleopatra mandarin seedlings was reduced (Zekri, 1991).

Reduction in leaf water potential was closely correlated with the decrease in leaf stomatal conductance. Leaf water potential and leaf water content of one-year-old Verna and Fino lemon trees, grown in nutrient solutions containing 40 or 80 mol m^{-3} NaCl, were markedly reduced (Nieves *et al.*, 1991a). Banuls and Millo-Primo, (1995) reported that leaf water potential was reduced more in grafted plants of salt-treated Navel orange than Clemantine mandarin.

Hydraulic conductivity of roots reduces by salinity. In a study with Sweet orange cv. Pineapple, Cleopatra mandarin and Trifoliata orange rootstocks decreased hydraulic conductivity of roots when grown at 15-60 mM NaCl saline conditions (Syvertsen and Yelenosky, 1988). Zekri and Parsons (1989) reported that decreased in root conductivity caused by NaCl at -0.20 and -0.35 MPa for some citrus rootstocks. These diminished for Sour orange and Cleopatra mandarin 19-30 %, for Trifoliata orange and Milam lemon (*C. jambhiri* hybrid) 78 to 85 %. Furthermore, a positive linear relationship occurs between root hydraulic conductivity and stomatal conductance (Zekri, 1991).

The mechanism by which salt stress affects gas exchange remains unknown. Lloyd and coworkers (1987, 1989, 1990) consistently found that stomatal conductance and CO_2 assimilation per unit leaf area were reduced similarly by salinity. They suggest three possible causes:

- The closure of stomata by salinity decreases mesophyll capacity for CO_2 assimilation,

- Salt stress reduces chloroplast capacity to fix CO_2 which produces a feedback signal to close the stomata,

- Salt stress impairs chloroplast metabolism and guard cell function simultaneously and independently.

Salinity seems to have little effect on photochemical reactions of chloroplast (Lloyd *et al*., 1987). Behboudian *et al.* (1986) reported that the rate of photosynthesis was correlated with leaf chlorophyll content which was decreased by salinity. Some studies was indicated that both increased and decreased leaf chlorophyll contents in response to salinity (Lloyd *et al*., 1987; Syvertsen and Yelenosky, 1988).

FACTORS AFFECTING CITRUS RESPONSE TO SALINITY

Rootstocks

Salt tolerances of citrus rootstocks are differed. Rootstocks that differ in the absorption and transport sodium and chloride ions have different salinity tolerances. Many studies (Kelley and Thomas, 1920; Grieve and Walker, 1983; Syvertsen and Yelenosky, 1988; Gallasch and Dalton, 1989; Alva and Syvertsen, 1991; Banuls and Millo-Primo, 1995) reported that salt tolerance of citrus was closely related to the chloride accumulation properties of the rootstocks. The mechanism which determines salinity tolerance is by restrictly the accumulation of saline ions (i.e., Na^+ and Cl^-) (Maas and Hoffman, 1977).

There are differences in the rate of chloride and sodium uptake between rootstocks. Cooper and Gorton (1952) reported that Rangpur lime and Cleopatra mandarin accumulated chloride at a slow rate (71-124 mg kg^{-} d^{-1}), rough lemon and sour orange at a medium rate (248-298 mg kg^{-} d^{-1}), and Calamondin (*C. madurensis* Lour) and Etrog citron at the fastest rate (348-515 mg kg^{-} d^{-1}). Table 1 summarizes reports which graded rootstocks according to their EC_e tolerances. According to Table 1 grapefruit is one of the least salinity sensitive rootstocks. Another criterion for rootstocks tolerance to salinity is yield stability and leave injury. For example, at EC_e 2.5 dS/m yield reduction of grapefruit rootstock is limited to less than 10% of its maximum and at EC_e 5 dS/m leaf injury not observed (Table 1).

Table 1. Tabulated summary of citrus rootstocks' tolerance to salinity.
Çizelge 1.Turunçgil anaçlarının tuzluluğa karşı tolearansları.

Rootstock	EC_e (dS/m)[1]	EC_w (dS/m)[2]	Source
Citrumelo 4475		2.0	Maas, 1986[2]
Trifoliata orange		2.0	Maas, 1986[2]
Cuban Shaddock		2.0	Maas, 1986[2]
Calamondin		2.0	Maas, 1986[2]
Sweet orange	1.0	2.0	Bernstein, 1980[1]; Maas, 1986[2]
Savage citrange	1.0	2.0	Bernstein, 1980[1]; Maas, 1986[2]
Rush citrange	1.0	2.0	Bernstein, 1980[1]; Maas, 1986[2]
Troyer citrange	1.0	2.0	Bernstein, 1980[1]; Maas, 1986[2]
Sampson tangelo	1.5	3.0	Bernstein, 1980[1]; Maas, 1986[2]

[1] Upper salinity limit in soil extract, yield reduction ≤ 10 %.
[2] Upper salinity limit in soil extract, without leaf injury.

Table 2 is similar to Table 1 but it includes the sensitivity of the rootstocks to EC_w- the electrical conductivity of the irrigation water. From Table 2 it seems that even with high water quality (EC_w 1.7 dS/m) yield of citrus is affected.

Leaf injury and defoliation of rootstocks are closely correlated with leaf chloride concentration (Kelley and Thomas, 1920; Banuls and Millo-Primo, 1995). Highly saline solutions (3.8 dS/m) caused necrotic burn symptoms at Duncan grapefruit and Valencia orange trees (Romero and Syvertsen, 1996).

Calcium restricted uptake and subsequent translocation of Na^+ to the leaves and increased K concentration in both roots and leaves. However, in plants that grafted on Cleopatra mandarin rootstock increasing Ca levels seemed to reduce

Table 2. Rootstock grading according to EC_e and EC_w.
Çizelge 2. EC_e ve EC_w 'a göre anaçların derecelenmesi.

Rootstock	EC_e (dS/m)[1]	EC_w (dS/m)[2]	Source
Citrumelo 4475	1.0	0.67	Sanchez and Silvertooth, 1996[1,2]
Trifoliata orange	1.0	0.67	Sanchez and Silvertooth, 1996[1,2]
Cuban shaddock	1.0	0.67	Sanchez and Silvertooth, 1996[1,2]
Calamondin	1.0	0.67	Sanchez and Silvertooth, 1996[1,2]

Sweet orange	1.0	0.67	Gallasch and Dalton, 1989[2]; Lloyd, *et al.*, 1990[2]; Sanchez and Silvertooth, 1996[1,2]
Savage citrange	1.0	0.67	Sanchez and Silvertooth, 1996[1,2]
Rush citrange	1.0	0.67	Sanchez and Silvertooth, 1996[1,2]
Troyer citrange	1.0	0.67	Sanchez and Silvertooth, 1996[1,2]
Sampson tangelo	1.5	1.0	Sanchez and Silvertooth, 1996[1,2]
Rough lemon	1.5	1.0	Zekri and Persons, 1989[2]; Banuls *et al.*, 1991[2]; Zekri, 1991[2]; Sanchez and Silvertooth, 1996[1,2]
Sour orange	1.5	1.0	Zekri and Persons, 1989[2]; Levy and Shalhevet, 1990[2]; Nieves *et al.*, 1991b[2]; Banuls *et al.*, 1991; Zekri, 1991[2]; Sanchez and Silvertooth, 1996[1,2]
Ponkan mandarin	1.5	1.0	Sanchez and Silvertooth, 1996[1,2]
Sunki mandarin	2.5	1.66	Sanchez and Silvertooth, 1996[1,2]
Grapefruit	2.5	1.66	Sanchez and Silvertooth, 1996[1,2]
Cleopatra mandarin	2.5	1.66	Gallasch and Dalton, 1989[2]; Zekri and Persons, 1989[2]; Nieves *et al.*, 1990[2]; Levy and Shalhevet, 1990[2]; Banuls *et al.*, 1991[2]; Zekri, 1991[2]; Sanchez and Silvertooth, 1996[1,2]
Rangpur lime	2.5	1.66	Sanchez and Silvertooth, 1996[1,2]

[1] Electrical conductivity of soil extract

[2] Electrical conductivity of irrigation water

transport of Na from roots to leaves, and Na accumulation in roots was associated with reduced concentration of K (Banuls *et al.*, 1991). Macrophylla rootstock accumulated more chloride than sour orange and the growth of the second rootstock was better (Nieves *et al.*, 1991 a). In addition, Alva and Syvertsen (1991) reported that Valencia orange trees grafted on Sour orange rootstock had higher potassium and calcium, but lower magnesium and chloride than trees on Carrizo citrange when irrigated with salinized (EC_w of about 0.3 , 1.6 and 2.5 dS/m) irrigation water.

Tolerance of citrus varieties to salinity varies according to rootstock. A variety budded on a rootstock is resistant to salinity while on other rootstock may be sensitive to salinity. (Wutscher, 1979; Rouse *et al.*, 1986). According to Grieve and Walker (1983), *Poncirus trifoliata* L. and Troyer citrange rootstocks allow relatively large amounts of chloride to enter the scion while *P. trifoliata* also exhibited a marked sodium exclusion capability at salinity range from 0.6 to 5.0 dS/m. Levy and Shalhevet (1990) reported that under high salinity, Cl accumulation in grapefruit and orange trees was low on Cleopatra mandarin and sour orange, but increased on rough lemon.

The reduction in relative growth caused by salt treatments was more scion (*Citrus sinensis* and *C. clemantine*) dependent, whereas defoliation was more rootstock (*C. reticulata* and *C. sinensis* x *P. trifoliata*) dependent. Scions on Cleopatra mandarin accumulated less Cl in their leaves and roots than did scions on Troyer citrange. Salinity decreased sharply the nitrogen content of leaves and roots in plants on Troyer citrange (Banuls *et al*., 1990).

Scion

Although Cl^- transport to scion is regulated primarily by rootstock, some evidence suggests that the scion itself limits Cl^- accumulation in some scion-rootstock combinations. With Na^+ accumulation, restriction or demands by scion may be as important as that of the rootstock (Maas, 1993). Cooper *et al*. (1952) reported that leaves on Shary Red grapefruit scions accumulated significantly more Na^+ than those on Valencia orange scions whether the rootstocks were Cleopatra mandarin or sour orange. In contrast, Cl^- accumulation, which was about 10 times greater than that of Na^+, was controlled by the rootstock, not the scion. Analysis of leaves on two different lemon scions on sour orange rootstock after a 3-year salinity treatment indicated that Na^+, and possibly Cl^-, were higher in Primo fiori scions than in Verna scions (Cerda *et al*., 1979).

Banuls *et al*. (1990) found that Navel orange accumulated much more Cl^- than did Clementine mandarin when budded on Cleopatra mandarin, whereas there was no difference when budded on Troyer citrange. In contrast, Behboudian *et al*. (1986) reported that no differences in Cl^- concentrations of leaves of Valencia orange, Taylor lemon, and Ellendale tangor scions grafted on Cleopatra mandarin. Nor was there any difference between rough lemon on its own roots and Valencia orange on rough lemon. In these cases, rootstock characteristics may have dominated. There were significant differences in Na^+ concentrations among scions. The mechanism employed by some scions to reduce the transport of ions is unknown, but ion transport is undoubtedly related to the growth and vigor of the scion and its water requirements (Maas, 1993).

Fertilization

Salinity affects citrus growth by inducing nutritional imbalances. High concentrations of monovalent salts in the rooting zone can reduce plant uptake of calcium and bicarbonate induced deficiencies of the micronutrients as Fe, Zn and Mn (Sanchez and Silvertooth, 1996).

Nutrition may affect the salt tolerance of citrus plant. The interactions among soil fertility, salinity, yield, and quality of citrus are of major concern to those interested in maximizing crop production in arid or semiarid areas. Calcium in the irrigation water may improve growth of orange seedlings under saline conditions (Zekri and Parsons, 1990a). Calcium restricted uptake and subsequent translocation of Na to the leaves and increased K concentration in both roots and leaves. However, in Navel orange trees budded on Cleopatra mandarin increasing Ca levels seemed to reduce transport of Na from roots to leaves, while Na accumulation in roots was associated with reduced concentration of K in Cleopatra mandarin rootstock (Banuls *et al*., 1991). Alva and Syvertsen (1991) reported that Valencia orange trees on Sour orange had higher potassium and calcium concentration in the organs, but lower magnesium and chloride than trees on Carrizo citrange when irrigated with salinized (EC_w of about 0.3 , 1.6 and 2.5 dS/m) irrigation water.

Addition of calcium (as calcium acetate) increased growth and halved defoliation of salt stressed sweet orange cv. Hamlin trees. Furthermore, calcium acetate decreased the concentrations of Cl and Na in the leaves, and increased photosynthesis and stomatal conductance. Calcium acetate also counteracted the reductations in leaf water and osmotic potentials induced by salinity. In addition, calcium acetate inhibited the accumulation of proline in the leaves which affected the reduction in osmotic potential (Banuls and Millo-Primo, 1992).

Climatic Factors

Salinity stress is highly sensitive to interactions with climatic factors, exactly temperature, humidity and light intensity (Salim, 1989). The combined effects of salinity and conditions of high evaporative demand, whether caused by high temperature, low humidity, wind, or drought, are more stressful than salinity alone. They may modify citrus response to both toxic and osmotic effects of salinity. Generally, toxic reactions (leaf burns) occur under hot, dry conditions and may not appear under cool, humid weather even though leaves contain toxic concentrations of Cl^- or Na^+ (Bernstein, 1974). In other words, citrus is less resistant to salinity at high potential transpiration (hot, dry climate) than at low potential transpiration (cooler and more humid climate) (Ben-Asher, 1993).

Yields of many crops are adversely affected by the effects of air pollutants (Heck *et al*., 1982). Citrus is no exception (Thompson *et al*., 1972). For example, ozone, a major air pollutant in southern California, decreases the yield of some crops more under nonsaline than under saline conditions (Hoffman *et al*., 1973; Maas *et al*., 1973). The consequences of these interactions need to be taken into account when evaluating the response of citrus crops to soil salinity stress. Possibilities of a three-way interaction are indicated by results of Eissenstat *et al*. (1991) who reported that chronic ozone exposures dimished frost resistance, whereas moderate doses of ozone may increase frost resistance (Maas, 1993).

EFFECTS OF SALINITY ON YIELD OF CITRUS

Salinity reduces yield in trees. Yield response curves indicate that citrus can tolerate salinity up to a threshold level above which yields decline approximately linearly as salinity increases. Sanchez and Silvertooth (1996) reported 50%, 75%, 90%, and 100% of yield potential in response to the respective EC_e of 4.9 , 3.4 , 2.4 and 1.8 dS/m for grapefruit and orange.

There is a definite relationship between vegetative development (especially canopy volume) and yield. As a result, fruit yield decreases because of growth reduction under saline conditions.

Maas and Hoffman (1977) assessed yield response to salinity with two essential parameters. A threshold parameter which is the maximum allowable salinity without yield reduction, as that of nonsaline conditions. The second parameter is a slope describing the percent of yield decrease per unit salinity increase beyond that threshold.

Hence, relative yield can be calculated by the following equation:

$$Yr = 100 \qquad EC \leq Th$$
$$Yr = 100 - B\,(EC_e - Th) \qquad EC > Th$$

Yr = Relative yield (%)
B = The percent yield decrease per unit salinity increase above the threshold (% dS/m).
EC_e = The electrical conductivity of an extract of a saturated soil paste.
Th = The salinity threshold

Table 3 is a summary of some reported salinity parameters. According to this table the average threshold EC_e of many citrus varieties is l.1 dS/m and the yield loss is 18% per dS/m. The high sensitivity of citrus to salinity is indicated by the two parameters. First the threshold value varies from very low EC (0.45 dS/m) to moderately high EC (1.8 dS/m). Second, the slope of most citrus varieties is steeper than the slope of many other crops. It varies from 10% yield reduction per dS/m to 43% per dS/m.

Table 3. Salinity parameters of several citrus varieties.
Çizelge 3.Bazı turunçgil çeşitlerinin tuzluluk parametreleri.

Variety	Rootstock	Threshold (dS/m)	Slope (%per dS/m)	Source
Grapefruit		1.8	16	Hayward *et al.*, 1945; Maas and Hoffman, 1977
Grapefruit		0.45	14.5	Bielorai *et al.*, 1978
Orange		1.7	16	Heller *et al.*, 1973; Maas and Hoffman, 1977
Navel orange		1.0	12	Hardling *et al.*, 1958
Valencia orange		0.7	20	Chapman *et al.*, 1969
	Sour orange	1.5	10	Bernstein, 1969
	Sweet lime	1.0	10	Bernstein, 1969
Valencia orange	Troyer citrange	0.7	20	Birgham *et al.*, 1974
Shamouti	Sour orange	1.0	20	Heller *et al.*, 1973
Shamouti	Sweet lime	1.0	43	Shalhevet *et al.*, 1974

Lloyd and Howie (1989) obtained Washington Navel orange trees irrigated with 20 mol NaCl m^{-3} had a greater number of vegetative flushes in spring. This occurred at the expense of flowering, as numbers of reproductive and mixed flushes were reduced by salinity. Despite a high number of vegetative buds on trees irrigated with 20 mol m^{-3} NaCl, leaf area was still less than low salinity trees.

Nieves *et al.* (1990) are reported that fruit yield of lemon was progressively decreased by Cl^- concentrations that ranged from 6 to 42 mol m^{-3}.

LITERATURE

Ackerson, R. C., and V. B. Youngner. 1975. Responses of bermuda grass to salinity. Agron. J. 67: 678-681.

Alva, A. K., and J. P. Syvertsen. 1991. Irrigation water salinity affects soil nutrient distribution, root density, and leaf nutrient levels of citrus under drip fertigation. J. Plant Nutr.14: 715-728.

Banuls, J., F. Legaz, and E. Millo-Primo. 1990. Effects of salinity on uptake and distribution of chloride and sodium in some citrus scion-rootstock combinations. J. Hort. Sci. 65: 715-724.

Banuls, J., F. Legaz, and E. Millo-Primo. 1991. Salinity calcium interactions on growth and ionic concentration of citrus plants. Plant and Soil 133: 39-46.

Banuls, J., and E. Millo-Primo. 1992. Effects of chloride and sodium on gas exchange parameters and water relations of citrus plants. Physiologia Plantarum 86: 115-123.

Banuls, J., and E. Millo-Primo. 1995. Effects of salinity on some citrus scion-rootstock combinations. Ann. Bot. (London) 76: 97-102.

Behboudian, M. H., E. Törökfalvy, and R. R. Walker. 1986. Effects of salinity on ionic content, water relations and gas exchange parameters in some citrus scion-rootstock combinations. Sci. Hort. 28: 105-116.

Ben-Asher, J. 1993. A simplified model of integrated water and solute uptake by salts and selenium accumulating plants. Soil Sci. Soc. Am. J. 58: 1012-1016.

Bernstein, L. 1969. Salinity factors and their limits for citrus culture (H.D. Chapman, ed.). University of Calif., Riverside. Proc.1 st. Int. Citrus Sym. 3:1779-782.

Bernstein, L. 1974. Crop growth and salinity. Drainage for agriculture, Jan Van Schitgararde, Ed. Agron.17, Amer. Soc. of Agron., Madison, Wisc, pp. 39-54.

Bernstein, L. 1975. Effects of salinity and sodicity on plant growth. Ann. Rev. Phytopathol.,13: 295-312.

Bernstein, L. 1980. Salt tolerance of fruit crops. USDA Info. Bull. 292 (revised).

Bernstein, L. 1981. Effects of salinity and soil water regime on crop yields (*Ed* D. Yaron). U.S.A. 432 pp.

Bielorai, H., J. Shalhevet, and Y. Levy. 1978. Grapefruit response to variable salinity in irrigation water and soil. Irri. Sci. 1: 61-70.

Bielorai, H., S. Dasberg, Y. Erner, and M. Brum. 1986. Effect of various soil moisture regimes and fertilizer levels on citrus yield response under partial wetting of the root zone. Nordia-1977-1984. Alonha Notea 9: 1-27.

Bielorai, H., S. Dasberg, Y. Erner, and M. Brum. 1988. Effect of saline irrigation water on Shamouti orange production. Proc. Int. Citrus Cong. 6: 707-715.

Birgham, F. T., R. J. Mahler, J. Parra, and L. H. Stolzy. 1974. Long-term effects of irrigation salinity management on a Valencia orange orchard. Soil Sci. 117: 369-377.

Cerda, A., F. G. Fernandez, M. Caro, and M. G. Guillen. 1979. Growth and mineral composition of two lemon varieties irrigated with saline waters. Agrochimica 23: 387-396.

Cooper, W. C., and B. S. Gorton. 1952. Toxicity and accumulation of chloride salts in citrus on various rootstocks. Proc. Am. Soc. Hort. Sci. 59: 143-146.

Chapman, H. D., J. Harrietann, and D. S. Rayner. 1969. Effects of variable maintained chloride levels on orange growth, yield and leaf composition (*Ed* H. D. Chapman) University of Calif., Riverside Proc. lst Int. Citrus Symp. 3: 1811-1817.

Csizinszky, A. A. 1996. Considerations for salt management in soil and water for producing horticultural crops: introduction to the workshop. Hort Technology 6: 96.

Dasberg, S., H. Bielorai, Y. Erner, and M. Barum. 1986. The effect of saline irrigation water on Shamouti oranges. Volcani Center Agric. Res. Org. Rep. 304-0064.

Downton, W. J. S. 1977. Photosynthesis in salt-stressed grape vines. Aust. J. Plant Physiol. 4: 183-192.

Downton, W. J. S., S. Grant, W. J. R. Robinson, and S. P. Robinson. 1985. Photosynthetic and stomatal responses of spinach leaves to salt stress. Plant Physiol. 77: 85-88.

Dudeck, A. E., S. Singh, C. E. Giordana, T. A. Nell, and D. B. Mc Connell. 1983. Effects of sodium chloride on Cynodon turf grasses. Agron. J. 75: 927-930.

Eissenstat, D. M., J. P. Syvertsen, T. J. Dean, G. Yelenoky, and J. D. Johnson. 1991. Sensivity of frost resistance and growth in citrus and avocado to chronic ozone exposure. New Phytol. 118: 139-146.

Fischer, R. A., and R. M. Hagen. 1965. Plant water relations irrigation management and crop yield. Exp. Agr.l: 161-177.

Francois, L. E., and R. A. Clark. 1980. Salinity effects on yield and fruit quality of Valencia orange. J. Amer. Soc. Hort. Sci. 105: 109-202.

Gale, J. 1975. Water balance and gas exchange in plants under saline conditions. In: Poljakoff-Mayber A., Gale J., eds. Plants in saline environments (Ecological Studies 15) Springer-Verlag, New York.

Gallasch, P. T., and G. S. Dalton. 1989. Selecting salt-tolerant citrus rootstocks. Aust. J. Agr. Res. 40: 137-144.

Garcia, L. M. F., J. M. Ortiz, L. D. Garcia, and A. Cerda. 1993. Effect of salinity on growth, ion content and $C0_2$ assimilation rate in lemon varieties on different rootstocks. Physiologia Plantarum 89: 427-432.

Goell, A. 1967. Salinity effects on citrus trees. University of Calif., Riverside Proc. 1st. Int. Symp. 3: 1819-1823.

Grieve, A. M., and R. R. Walker. 1983. Uptake and distribution of chloride, sodium and potassium ions in salt-treated citrus plants. Aust. J. Agr. Res. 34: 133-143.

Hardling, R. B., P. F. Praat, and W. W. Jones. 1958. Changes in salinity, nitrogen and soil reaction in differentially fertilized-irrigated. Soil Sci. 88: 177-184.

Hayward, H. E., B. Cooil, and W. Spurr. 1945. Tolerance of Marsh grapefruit to chloride salts. U.S: Salinity Lab., Report to Col., Riverside, California. pp. 49-50.

Heck, W. W., O. C. Taylor, R. Adams, G. Bingham, J. Miller, E. Preston, and L. Weinstein. 1982. Assessment of crop loss from ozone. J. Air Pollut. Contr. Assoc. 32: 353-361.

Heller, J., J. Shalhevet, and A. Goell. 1973. Response of citrus orchard to soil moisture and soil salinity. *In:* Physical aspects of soil water and salt in ecosystems. Ecological Studies 4: 409-419.

Howie, H., and J. Lloyd. 1989. Response of orchard Washington Navel orange, *Citrus sinensis* L. Osbeck to saline irrigation water: II. Flowering, fruit set and fruit growth. Aust. J. Agr. Res. 40: 371-380.

Jennings, D. H. 1968. Halophytes, succulence and sodium in plants- A unified theory. New Phytologist 67: 899-911.

Kelley, W. P., and E. E. Thomas. 1920. The effects of alkali on citrus tree. Cal. Agr. Exp. Sta. Bul. 318: 303-337.

Levy, Y., J. Shalhevet, and H. Bielorai. 1979. Effect of irrigation regime and water salinity on grapefruit quality. J. Amer. Soc. Hort. Sci. 104: 356-359.

Levy, Y., and J. Shalhevet. 1990. Ranking the salt tolerance of citrus rootstocks by juice analysis. Scientia Hort. 45 (1-2): 89-98.

Lloyd, J., J. P. Syvertsen, and P. E. Kriedemann. 1987. Salinity effects on leaf water relations and gas exchange of Valencia orange, *Citrus sinensis* L. Osbeck on rootstocks with different salt exclusion characteristics. Aust. J. Plant Physiol. l4: 605-617.

Lloyd, J., and H. Howie. 1989. Response of orchard Washington Navel orange, to saline irrigation water. I. canopy characterists and seasonal patterns in leaf abscission, osmotic potential and concentrations of carbohydrates, sodium and chloride. Aust. J. Agr. Res. 40: 359-370.

Lloyd, J., P. E. Kriedemann, and D. Aspinall. 1989. Comparative sensitivity of Prior Lisbon lemon and Valencia orange trees to foliar sodium and chloride concentrations. Plant, Cell and Envir.12: 529-540.

Lloyd, J., P. E. Kriedemann, and D. Aspirall. 1990. Contrasts between *Citrus* spp. In response to salinization: An analysis of photosynthesis and water relations for different rootstock-scion combinations. Physiologia Plantarum 78: 236-246.

Longstreth, D. J., and P. S. Nobel. 1979. Salinity effects on leaf anatomy. Plant Physiol. 63 : 700-703.

Maas, E. V., G. J. Hoffman, S. L. Rawlins, and G. Ogata. 1973. Salinity-ozone interactions on pinto bean: Integrated response to ozone concentration and duration. J. Environ. Qual. 2: 400-404.

Maas, E. V., and G. J. Hoffman. 1977. Crop salt tolerance current assessment. J. Irr. And Drainage Division, ASCE 103 (IR2): 115-134.

Maas, E. V. 1986. Salt tolerance of plants. App. Agr. Res.1(1): 12-26.

Maas, E. V. 1990. Crop salt tolerance. *In:* Agric. Salinity Assessment and Management. Ed. K.K. Tanji. Amer.Soc. Civil Eng. Manuals and Reports on Engineering No.71, ASCE, New York, pp. 262-304.

Maas, E. V. 1993. Salinity and citriculture. Tree Physiology 12, 195-216.

Nieves, M., V. Martinez, A. Cerda, and M. G. Guillen. 1990. Yield and mineral composition of Verna lemon trees as affected by salinity and rootstock combination. J. Hort. Sci. 65: 359-366.

Nieves, M., A. Cerda, and S. Navarro. 1991a. Plant growth, accumulation and distribution of chloride, sodium and potassium in two lemon rootstocks. Suelo Planta 1(1): 117-126.

Nieves, M., A. Cerda, and M. Botella. 199lb. Salt tolerance of two lemon scions measured by leaf chloride and sodium accumulation. J. Plant Nutr.14 (6): 623-636.

Nieves, M., A. Garcia, and A. Cerda. 1991c. Effects of salinity and rootstock on lemon fruit quality. J. Hort. Sci. 66(1): 127-130.

Rause, R. E., H. W. Browning, C. R. Bogle, and C. C. Cannolly. 1986. Rebuilding the citrus industry in Texas. Texas Agr. Expt. Sta. MP-1596.

Rendig, V. V., and M. H. Taylor. 1989. Principles of soil-plant interrelationships. Mc Grow Hill Publishing Company. USA 275 pp.

Rokba, A. M., M. N. Abdel-Messih, and M. A. Mohammed. 1979. Breeding and screening some citrus rootstocks for salt tolerance in Egypt. Egypt J. Hort. 6: 69-79.

Romero-Aranda, R., and J. P. Syvertsen. 1996. The influence of foliar-applied urea nitrogen and saline solutions on net gas exchance of Citrus leaves. J. Amer. Soc. Hort. Sci.121: 501-506.

Rouse, R. E., H. W. Browning, C. R. Bogle, and C. C. Connolly. 1986. Rebuilding the citrus industry in Texas. Texas Agr. Expt. Sta. MP-1596.

Ruan, Y., L. Zhang , G. Wu, and S. Zhang. I988. The effect of water stress on photosynthesis on Citrus unshiu Marc. Acta Hort. Sinica 15: 93-98.

Salim, M. 1989. Effects of salinity and relative humidity on growth and ionic relations of plants. New Phytology 113: 13-20.

Sanchez, A. C., and J. C. Jeffrey. 1996. Managing saline and sodic soils for producing horticultural crops. Hort Technology 6: 99-107.

Shalhevet, J., D. Yaron, and D. Horowitz. 1974. Salinity and citrus yield analysis of results from a salinity survey. J. Hort. Sci. 49: 15-27.

Shalhevet, J. P., and Y. Levy. 1990. Citrus tree (*Eds.* B. A. Stewart and D. R. Nielson). Irr. Agr. Crops. Number 30 in the series Agronomy. USA. pp. 951-986.

Syvertsen, J. P., and G. Yelenosky. 1988. Salinity can exchance freeze tolerance of citrus rootstock seedling by modifying growth, water relations, and mineral nutrition. J. Amer. Soc. Hort. Sci. 113: 889-893.

Thompson, C. R., G. Kats, and E. Hensel. 1972. Effects of ambient levels of ozone on Navel oranges. Environ. Sci. Tech. 6: 1014-1016.

Walker, R. R., E. Torokfalvy, and W. J. S. Downton. 1982. Photosynthetic responses of the citrus varieties Rangpur lime and Etrog citron to salt treatment. Aust. J. Plant Physiol. 9: 783-790.

Wutscher, H. K. 1979. Citrus rootstocks. Hort. Rev. l: 237-269.

Zekri, M., and L. R. Parsons. 1989. Growth and root hydraulic conductivity of several rootstocks under salt and polyethylene glycol stresses. Physiologia Plantarum 77: 99-106.

Zekri, M., and L. R. Parsons. 1990a. Calcium influences growth and leaf mineral concentration of citrus under saline conditions. Hort Science 25: 784-786.

Zekri, M., and L. R. Parsons. 1990b. Comparative effects of sodium chloride and polyethylene glycol on shoot distribution, growth and stomatal conductance of sour orange and Cleopatra mandarin seedlings. Plant and Soil 129: 137-144.

Zekri, M. and L. R. Parsons. 1990c. Response of split-root sour orange seedlings to sodium chloride and polyethylene glycol stresses. J. Exp. Bot. 41: 35-40.

Zekri, M. 1991. Effects of sodium chloride on growth and physiology of sour orange and Cleopatra mandarin seedlings. Scientia Hort. 47: 305-316.

Zekri, M., and L. R. Parsons. 1992. Salinity tolerance of citrus rootstocks: Effects of salt on root and leaf mineral concentrations. Plant and Soil 147: 171-181.

Zekri, M. 1993a. Salinity and calcium effects on emergence, growth and mineral composition of seedlings of eight citrus rootstocks. J. Hort. Sci. 68: 53-62.

Zekri, M. 1993b. Seedling emergence, growth, and mineral concentration of tree citrus rootstocks under salt stress. J. Plant Nutr.16: 1555-1568.