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The Response of Several *Citrus* Genotypes to High-salinity Irrigation Water

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Abstract. The effect of irrigation with saline water on several citrus genotypes was evaluated in a short-term field experiment. Salinity levels ranged from 2.0 to 6.4 $dS\cdot m^{-1}$. Comparatively salt-tolerant *Citrus* species and *Citrus* x *Poncirus* hybrids were tested for their possible use as rootstocks for commercial citrus cultivars irrigated with brackish water. All the tested genotypes survived the highest salinities. At all salinity levels, the best chloride excluder was Cleopatra mandarin (*Citrus reshni* Hort. ex Tan.), and the worst was sour orange (*C. aurantium* L.). Gou Tou Cheng (*C. aurantium* hybrid?) and Rangpur (*C. limonia* Osb.) x Troyer citrange (*C. sinensis* L. x *Poncirus trifoliata* L.) RT803 were found to be promising genotypes for further evaluation as rootstocks tolerant to high salinities. Rangpur was unsuitable because of foot rot.

Citrus is a salt-sensitive crop. Like many woody fruit crops, it can accumulate Cl^- or Na^+, or both, to toxic levels in plant tissues (Bernstein, 1980; Mass, 1996; Shalhevet and Levy, 1990). Oppenheimer (1937) was the first to report the effect of saline water on citrus rootstocks. Mature orange trees on sour orange (SO) rootstock accumulated less Cl^- in the scion leaves than did trees on Palestine sweet lime (*C. limettioides* Tan.). Irrigation with saline water did not lead to the accumulation of Na in the scion regardless of rootstock. Later studies, mainly on potted seedlings (Cooper and Gorton, 1952), ranked the rate of Cl^- uptake among the citrus genotypes. Cleopatra mandarin (CLEO) and Rangpur (RANG) accumulated Cl^- at a "slow rate," and rough lemon (*C. jambhiri* Lush.) and SO at a "medium rate." These results were later confirmed in many other studies (Francois and Clark, 1980; Zekri and Parsons, 1992). The response of field-grown trees differs from that of potted seedlings (Levy and Shalhevet, 1990, 1991). For mature, fruit-bearing trees, there was a small advantage to CLEO over SO, while rough lemon rootstock was very salt-sensitive. The difference in response between potted seedlings and field-grown trees may be attributed to the distinction between pot-bound root systems, or sand culture (Zekri and Parsons, 1992), and the root systems of field-grown trees. CLEO and RANG remain the best salt-tolerant rootstocks available. Improved citrus tristeza virus (CTV)-tolerant rootstocks, with tolerance to salinity similar to or better than SO, are needed.

Salinity data on fruit and nut trees are scarce because of the long-term and complex nature of the research (Mass, 1996). The method of double-emitter source (DES; De Malach et al., 1996) provides a new tool for achieving a salinity gradient, and can be used to study the response of different genotypes to salinity under orchard conditions. In this study, we compared new, apparently CTV- and salinity-tolerant genotypes for their possible use as rootstocks in citrus orchards irrigated with brackish water.

Materials and Methods

Plant material. The genotypes that were studied in this work were: CLEO; Gou Tou Cheng (GT); RANG; SO; Rangpur x Troyer (RT803), originally named C-54-64-32; Sunki x Benecke (SB812), originally named C-65-165; and, later, HRS812. Both crosses were made by J. Furr in Indio, Calif. (Furr and Ream, 1969).

Most RANG trees died from attack by *Phytophthora* and are therefore not included in this report. This is not surprising, since in Israel RANG, more than any commercial rootstock, may become infected with foot rot, which is not detected in the nursery but becomes severe after transplanting (Levy et al., 1980).

Location. One-year-old seedlings of the different genotypes were planted in the field at the Ramat haNegev Desert Agro-Research Center at 31°05´N and 34°41´E, elevation ≈300 m, and mean annual rainfall (winter only) <100 mm. The soil is light loess (eolian sandy loam) with 5% to 8% clay and a pH of 8.0–8.4.

Experimental design. Four salinities were applied with DES (De Malach et al., 1996) at increasing levels along the rows. Salinity ranged from 2.0 to 6.4 $dS\cdot m^{-1}$ in four linear steps. Each salinity level was applied to groups of three plants in each row. With no buffer trees between the different salinity treatments, the first tree at a given salinity was partially influenced by the salinity of the previous treatment, while the last was affected by the subsequent treatment, actually producing a linear salinity gradient. The salinity gradients were replicated in two blocks, with the salinity vectors (increase in salinity) in opposing directions. The genotypes were planted in parallel rows, with a total of six plants for each salinity. The plants were drip irrigated and fertigated three times a week. The salinity regime was imposed from the day of planting and the data presented here were collected after two summers of salinization.

Water. The local well water (highest salinity) had an electrical conductivity (EC_i) of 6.4 $dS\cdot m^{-1}$; ions ($mol\cdot m^{-3}$) were: 47.3 Cl^-, 44.4 Na^+, 4.5 Ca^{++}, 3.5 Mg^{++}, 4.5 SO_4^{--}, and 5.0 HCO_3^-.

Measurements. Observations, measurements, and chemical analyses were made on individual trees. A running mean of three trees was used to analyze the plant response, and a similar running mean was calculated for the EC_i values.

Twenty spring-flush leaves were collected from each tree at the end of September. Leaves were weighed within 3 h of collection, washed in dilute detergent (Nonidet; BDH Co., Poole, England), and dried in a ventilated oven at 65 °C. Pulverized leaf material (100 mg) was shaken for >4 h in 5 mL of water; Cl^- was determined with a chloride meter, and total Na and K with a flame photometer.

Thresholds and slopes of the effect of salinity on growth were calculated by nonlinear analysis (PROC NLIN; SAS Inst., 1985)

Results and Discussion

Seedlings of all genotypes survived the highest salinity level with no apparent toxicity symptoms such as leaf-burn, chlorosis, or defoliation. Growth of all genotypes was reduced at a similar rate (slope) as salinity increased regardless of their Cl^- or Na uptake (Fig. 1). Similar results were reported earlier (Garcia-Legaz et al., 1993; Syvertsen et al., 1993; Zekri and Parson, 1989, 1990). How-

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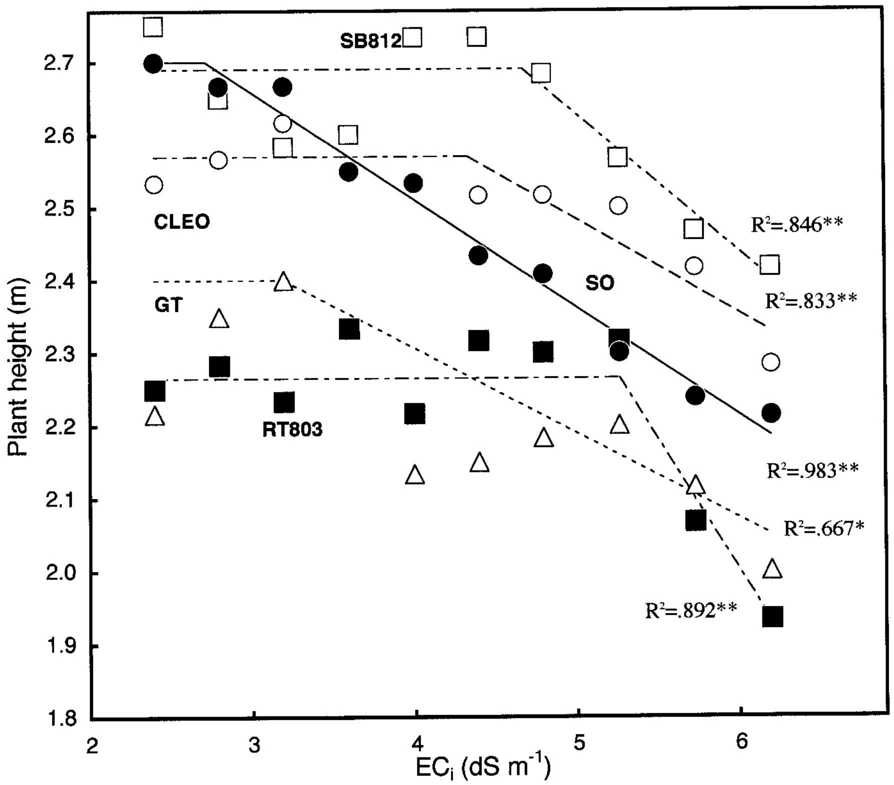

Fig. 1. The effect of irrigation water salinity (EC$_i$) on tree height of seedlings of five *Citrus* genotypes. Lines were calculated by nonlinear (NLIN) procedure. GT lines did not converge, height was reduced from 2.3 m at a threshold of 3.2 dS·m^{-1} at a rate (slope) of –2.71% per dS·m^{-1}. CLEO height was reduced from 2.6 ± 0.02 m at a threshold of 4.34 ± 0.32 dS·m^{-1}, slope = –2.98 ± 0.73% per dS·m^{-1}. Height of SB812 was reduced from 2.7 ± 0.02 m at a threshold of 4.68 ± 0.27 dS·m^{-1}, slope = –4.04 ± 1.03% per dS·m^{-1}. Height of SO was reduced from 2.7 ± 0.30 m at a threshold of 2.72 ± 0.21 dS·m^{-1}, slope = –5.43 ± 0.30% per dS·m^{-1}. RT lines did not converge, height was reduced from 2.3 m at a threshold of 5.27 dS·m^{-1}, slope = –6.83% per dS·m^{-1}.

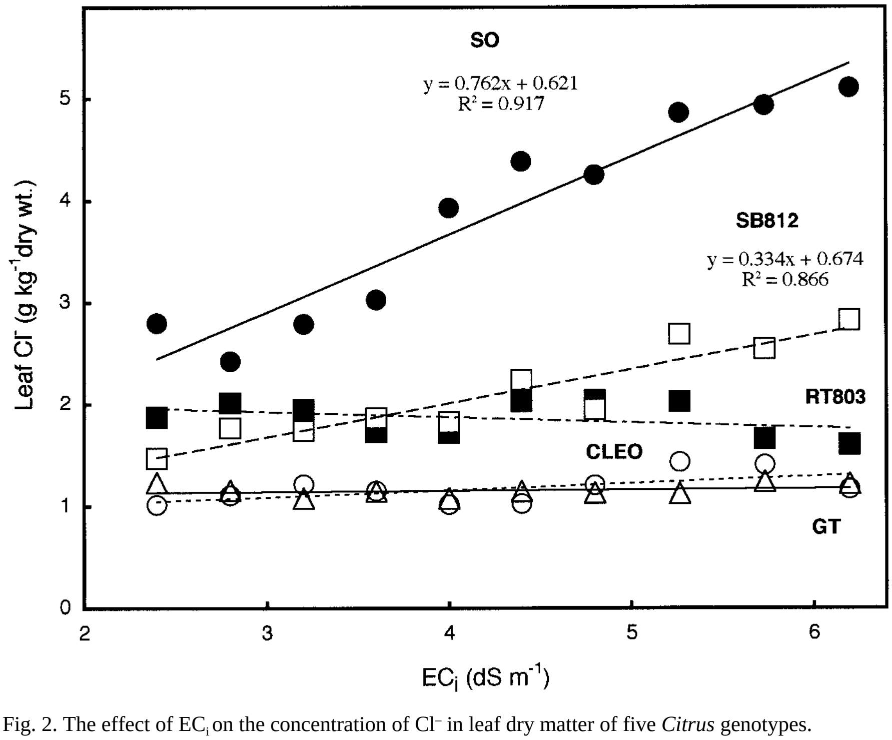

Fig. 2. The effect of EC$_i$ on the concentration of Cl$^-$ in leaf dry matter of five *Citrus* genotypes.

ever, the thresholds were not the same for all genotypes. SO had the lowest threshold and RT803 and SB812 the highest. The regression was poor in GT, because of the large variability typical for this genotype. Growth can be hampered by low osmotic potential of the soil solution, as with most plants, in addition to the effect of specific ion toxicity (Maas, 1993).

The most Cl$^-$-tolerant genotypes were CLEO and GT (Fig. 2). Most of the new genotypes proved better than SO in terms of leaf Cl$^-$ accumulation and growth. These genotypes are candidates to replace SO as a rootstock, but should be tested thoroughly for their disease tolerance and effects on yields, fruit quality, and longevity.

The concentrations of Cl$^-$ in leaves of nongrafted genotypes were relatively low (<6 g·kg^{-1} dry weight), in comparison with levels found in mature grafted citrus trees (Levy and Shalhevet, 1990, 1991; Shalhevet and Levy, 1990). GT, RT803, and CLEO did not accumulate much Cl$^-$. The genotype that accumulated most Cl$^-$ was SO, which, in a mature orchard, proved relatively tolerant to salinity (Levy et al., 1992).

The level at which Cl$^-$ accumulation in the leaves becomes toxic is not clear. Cole (1985) reported that concentrations >2.5 g·kg^{-1} dry weight in 'Valencia' orange on rough lemon reduced yield. Chapman (1968) suggested 7.5 g·kg^{-1} Cl$^-$ as the maximum permissible level. Furr and Ream (1969), however, reported no leaf burn at concentrations <20 g·kg^{-1}. Similar results were obtained in mature trees in the Negev desert of Israel, where relatively high Cl$^-$ levels in the leaves did not cause leaf burn, but did cause premature (green) leaf abscission. High Cl$^-$ concentration in leaf tissue may damage citrus, which is apparent in the loss of chlorophyll (bronzing). This damage and the reduction in photosynthesis are well documented (Carter and Myers, 1963; Garcia-Legaz et al., 1993; Lloyd et al., 1987; Romero-Aranda and Syvertsen, 1996; Zekri, 1991). The reduction in photosynthesis may inhibit growth and lead to autumn and winter defoliation. The cumulative deleterious effect of salinity can result in Cl$^-$ levels >20 g·kg^{-1} leaf dry weight and reduce yield significantly after 2 to 3 years, especially in high-yielding species such as grapefruit (*C. paradisi* Macf.) (Levy and Shalhevet, 1990).

In this study, a significant negative correlation was found between leaf Cl$^-$ concentration and growth of SO and SB812 (Fig. 3). Concentrations above 2 g·kg^{-1} were harmful for SO and SB812 seedlings, in contrast with mature trees grafted on SO (Levy and Shalhevet, 1990).

The ultimate productivity (fruit yield and quality) of citrus on these rootstocks will depend on the interactions of many factors, including cultivar–rootstock compatibility, cultural practices, tree age, and edaphic conditions. However, nongrafted genotypes that did not accumulate Cl$^-$ for 2 years at extreme salinity levels, should tolerate salinity better than genotypes such as SO, which accumulated Cl$^-$ as salinity levels increased. The low osmotic potential associated with increased

EC_i will probably reduce the growth of such Cl^--tolerant trees, as it does in most field crops (Fig. 1). However, it will not cause the total collapse of trees because of accumulation of Cl^- to toxic levels.

The best Cl^- excluding genotypes were CLEO, GT and RT803. Results obtained for RT803 were not expected, since it is a hybrid of Troyer citrange. The latter ranks among the most Cl^--sensitive genotypes (Levy and Lifshitz, 1995; Levy and Shalhevet, 1990). Both SO and SB812 accumulated Cl^- as salinity increased. In terms of Cl^- exclusion, SB812 performed better than did SO when data were expressed on a dry weight basis (Fig. 2).

The relative success of *Poncirus* crosses with the salinity-tolerant Rangpur and Sunki is encouraging. This proves the feasibility of selecting better salt-tolerant rootstocks from crosses of *Poncirus* with relatively salt-tolerant *Citrus* species, especially CLEO. However, regardless of their salinity and CTV tolerance, some of these crosses may be susceptible to citrus viroids (Levy, 1997) or to *Phytophthor*a (Furr and Ream, 1969).

Along with Cl^-, Na^+ is another toxic ion that can accumulate in leaves under saline conditions. CLEO accumulated more Na than did other genotypes (Fig. 4), as in previous studies (Cooper and Shull, 1953; Levy and Shalhevet, 1990; Levy et al., 1992; Taylor and Dimsey, 1993). The lack of adverse effects of Na may be linked to the high-pH, calcareous soil in this experiment. In sand culture, potted CLEO plants may suffer more than other rootstocks from salinity (Syvertsen et al., 1988). As a rootstock, CLEO performed better than did SO, which had lower levels of leaf Na, during a long-term experiment using the scions 'Marsh' grapefruit and 'Washington Navel' orange (Levy et al., 1992). CLEO is still the best Cl^- excluding rootstock ever found for citrus, and usually the best choice for Cl^- salinity conditions, although not for salinity caused by Na_2SO_4 and $MgSO_4$.

Conclusions

The results obtained in this experiment give hope that commercial citrus irrigation with brackish water may be feasible in the future, by using some of the genotypes investigated in this study. Among the new genotypes, SB812 absorbed some Cl^- but less than did SO. This genotype is promising as a rootstock in Florida (H. Wutscher, personal communication, 1998) and in Israel. GT is a candidate to replace SO, because of its tolerance to severe exotic isolates of CTV (Garnsey, 1993) and its apparent similarity to SO. Initial observations indicate that the growth rate of young orange trees grafted on it is as slow as those on CLEO, but significantly higher than on SO (Levy et al., 1996). The percentage of nucellar seeds may be low, and careful selection of seedlings will be needed in the nursery in order to achieve uniform trees. RT803 showed good tolerance to accumulation of both Cl^- and Na, even though it is a hybrid of Troyer citrange, but little is known about its performance as a rootstock. Hopefully it inherited from its Troyer

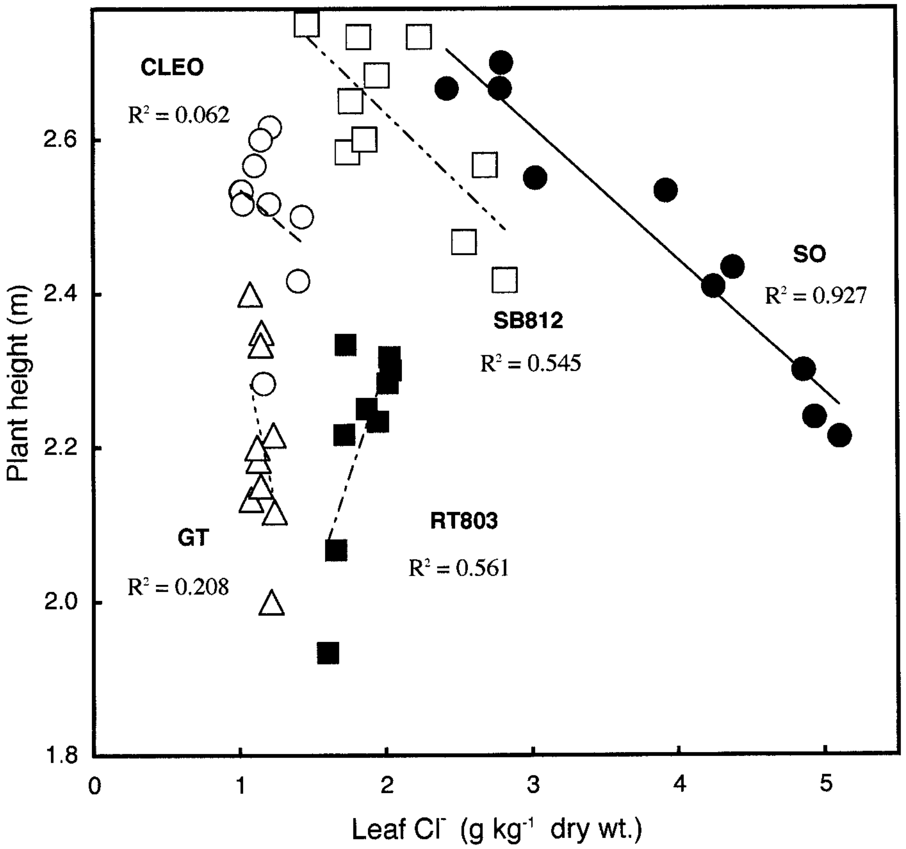

Fig. 3. Regression line models of tree height vs. concentration of Cl^- in leaf dry matter of five *Citrus* genotypes (only significant regression formulas are presented).

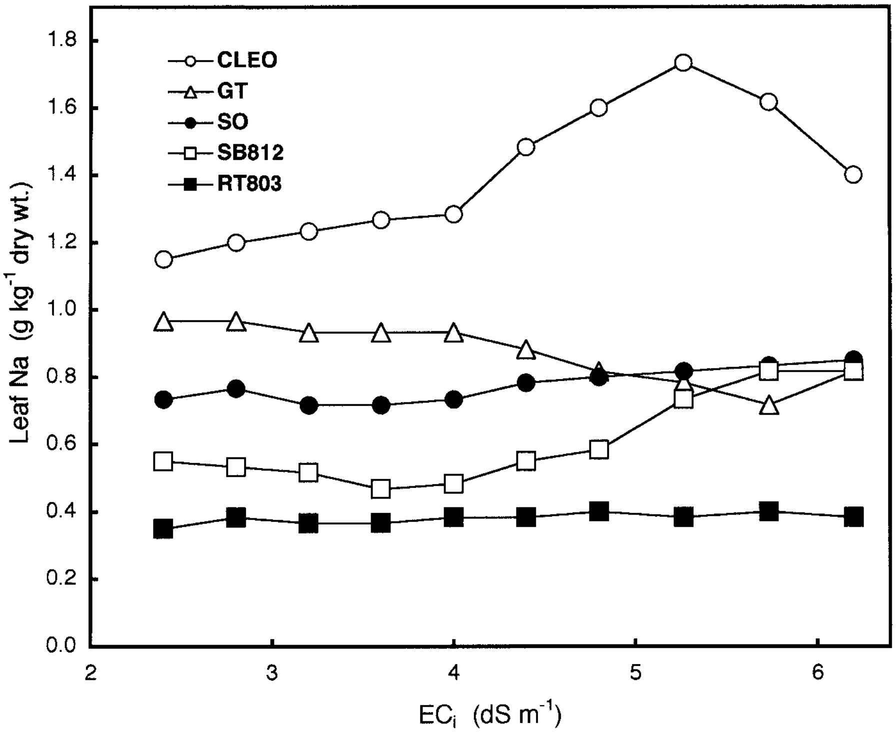

Fig. 4. The effect of EC_i on the concentration of Na in leaf dry matter of five *Citrus* genotypes.

parent resistance to *Phytophthora* and the ability to induce high fruit quality. Unlike reports from Texas (H. Wutscher, personal communication, 1998), it did not suffer from foot rot, which killed most of the Rangpur trees in our experiment.

Long-term rootstock–scion evaluation, which may require 10–20 years, will be needed to confirm these findings. One such experiment, employing an improved salinity gradient system and grafted trees, was planted in 1966 (Levy and Lifshitz, 1999). Long-term rootstock-salinity studies with commercial cultivars are needed to establish the economic basis for the utilization of brackish water for citrus.

Breeding of rootstocks should introduce new salinity-tolerant hybrids that will perform better than does CLEO. These genotypes can be tested for their salt tolerance in situ in short-term field experiments similar to the one reported here.

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