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ORIGINAL PAPER

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Trickle linear gradient for assessment of the salt tolerance of citrus rootstocks in the orchard

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Abstract Orchard trials on the effect of salinity on fruit tree rootstock combinations typically call for leaving border trees between treatments, thus limiting the number of combinations that can be evaluated and making these experiments expensive and rare. Five salinity dilution ratios were applied to orchard trees through regular drip lines by different combinations of regulated in-line drippers. This enabled the construction of an orchard experiment without border trees, with the salinity increasing linearly along the orchard rows. Leaf analysis after application of salinity for approximately 150 days revealed significant correlations between the applied dilution ratio and the concentrations of Cl, Na and K in the scion leaves of some of the rootstock combinations.

Introduction

Increased consumptive water use results in the inevitable degradation of ground water quality (Jensen et al. 1990). Most fruit crops are considered sensitive to salinity in comparison with field crops like cotton or wheat (Rhoades and Loveday 1990).

Most of the knowledge on the salinity tolerance of rootstocks comes from water culture or container experiments. However, the effects of cultural practices, particularly irrigation and salinity, on tree crops are cumulative (Hoffman et al. 1989; Levy et al. 1992; Shalhevet and Levy 1990). Pot experiments should be corroborated in long-term orchard experiments, which are comparatively rare (Hoffman et al. 1989).

The design of orchard irrigation experiments has to overcome the fact that the root systems of adjacent trees may overlap. The usual approach to eliminate the problem has been to leave ample border trees between different irrigation treatments. Studying different salinities in an orchard trial traditionally called for installing a metering (fertilizer) pump for each salinity, or serial irrigation phase; a large number of lateral water conduits to deliver the different waters to the different plots; and leaving border rows between the treatments. In a simple orchard experiment, 12 border trees were needed around each group of four experiment trees (Bielorai et al. 1978). The three salinity levels that were evaluated in the latter orchard experiment encompassed 288 trees, only 72 of which were experimental trees, covering about 1 ha. This experiment evaluated the effect of salinity on only one rootstock and one cultivar. Evaluation of different rootstock would have required ~1 ha per combination. Spreading the experiment over a large land area would have made soil heterogeneity a major obstacle in obtaining significant results, necessitating more replications. The size of the experiment becomes prohibitive, especially for an orchard experiment that should be run for many years in order to evaluate the cumulative effects.

Line source sprinkler irrigation (Hanks et al. 1976; Lauer 1983), which produces a linear gradient of fertilizer or salinity, proved a good way to overcome the border plots problem in field crops. However, this method is susceptible to winds and is usually not suitable for fruit trees, due to the planting distances. Overhead sprinkling cannot be used with saline water, further limiting the use of the line-source sprinkler gradient method.

Drip irrigation has become a major irrigation method for fruit trees grown under Mediterranean climate. It is the only method used for irrigation of citrus in the arid Negev region of Israel. Drip irrigation is particularly suitable for the utilization of saline water under desert conditions and higher levels of salinity can be tolerated with this system than with other methods of irrigation (Rhoades and Loveday 1990).

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A breakthrough in the design of drip-irrigation salinity experiments was achieved in the development of double-emitter source (DES, De Malach et al. 1996), which consisted of two parallel dripper lines and achieved the different salinities by coupling a combination of emitters with different discharges rates. This enabled us to study the orchard response of citrus genotypes to extremely high salinities (Levy et al. 1999). However, the main drawback of the DES system is that it employs two separate emitters; thus there is at least a remote danger that the salinity in the soil is not uniform. A modification of the method solved this problem by incorporating small mixing cans embedded in the ground under each pair of drippers, with the water overflowing from the cans to the soil (De Malach et al. 1996). However, the maintenance of thousands of open mixing cans for years in a long-term orchard experiment is a heavy burden.

The setup outlined below overcomes the mixing and the emitter problem. The different waters reach the soil after mixing through a regular emitter line, and the wetting pattern is exactly the same as that of commercial drip installations. This system makes feasible the design of multifactorial orchard experiments in a relatively small area, without border trees, by incorporating a gradient of salinity (or fertilizer) along the rows.

Materials and methods

The experiment was conducted in a citrus orchard planted especially for the purpose. Nucellar 'Marsh seedless' grapefruit (*Citrus paradisi* Macf.), grafted on ten different rootstocks, was planted on 1 July 1996, at a distance of 6×3 m, in sandy soil at the Besor Experiment Station in the southwest Negev, 31.15°N, 34.25°E.

Groups of 15 trees of each rootstock-scion combination were replicated in three randomized blocks. Groups of three trees along the row received different salinity levels, which increased linearly in five steps along the row. Different rootstock combinations were always in parallel rows. Thus, in the event that roots may reach adjacent rows, they would encounter the same soil salinities.

There were no border trees between the different salinities. The root systems of the trees would eventually overlap, thus the first tree in each group of three would be affected partially by the salinity of the preceding treatment and the third tree would be partially affected by the salinity of the succeeding treatment producing, essentially, a linear gradient along the row.

Water

The irrigation water consisted of the Shafdan reclaimed ground water, which had a chloride (Cl^-) concentration of ~220 mg · l^{-1}. Concentrated saline solution was prepared by dissolving $CaCl_2$ and NaCl at a ratio of 1:2 (w/w). This solution was injected into the irrigation system by a hydraulic fertilizer pump (Amiad), controlled by an irrigation computer (SAS Co.), which received its feedback from inline EC and temperature sensors. The irrigation water was collected during each irrigation cycle in each block in the orchard. Cl^- concentration was determined by Ag^+ ion titration with a Corning chloride meter, and Na and Ca were determined with a Corning flame photometer. The EC, and thus the Cl^- concentration of the manufactured saline water, was increased gradually during the first months of the experiment. At the end of summer the high salinity reached and EC of 2.2 dS m^{-1} before the addition of fertilizer, and Cl^- concentration ~485 mg · l^{-1}.

11	111222333444555	555444333222111	111222333444555	55

Fig. 1 The organization of different salinity dilution treatments along each row

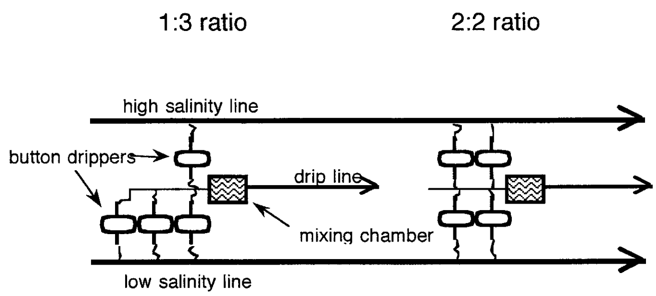


Fig. 2 Setup of the dilution system, each drip line irrigates a group of three trees

Dilution setup

The following setup was employed to achieve the different salinities in the field. Two parallel lateral pipes supplied each row of trees, one carrying water fo low (background) salinity and the other water with the highest salinity planned for the experiment.

A 9-m section of unregulated drip lines (TIRAN 17, Netafim Co.) was used to irrigate each group of three trees. Each section had twelve 4 l · h^{-1} inline emitters set 75 cm apart. The water to these sections was supplied from the two feeder laterals by four "wood packer" button compensated, non-leaking emitters, (Netafim Co.), regulated to deliver 12 l · h^{-1} each. The button emitters were connected in different combinations to the final TIRAN drip lines via a small inline mixing chamber constructed from a 65-mm pipe section (Fig. 1).

The sum of the regulated input was always 48 l · h^{-1}, which equalled the discharge of the 9-m section of TIRAN drip line. The ratio between the number of regulated button emitters connected to the different water sources determined the final salinity delivered by the drip line (see De Malach et al. 1996). Five dilution ratios were produced by using the ratios 4:0, 3:1, 2:2, 1:3 and 0.4. This was replicated three times along the row with the dilution vector in opposite directions (Fig. 2). The amount of irrigated water was equal in all salinities and all rootstocks.

Two border trees were left at each end of the row (total four) and received the salinity treatment of the adjacent experiment trees.

Plant material

The scion was nucellar 'Marsh seedless' grapefruit. The following rootstocks were used sour orange (*C. aurantium* L.), Vokameriana (*C. volkameriana* Chapot), Troyer citrange (*C. sinensis*×*Poncirus trifoliata*) and Rangpur lime (*C. limonia* Osbeck). The names of the different species follow the nomenclature of Hodgson (1967).

Culture practices

Drip irrigation was applied twice a week at about 15 l $tree^{-1}day^{-1}$; fertigation consisted of about 1000 ppm of NH_4NO_3. Iron chelate ethylenediamine di-(*o*-hydroxy-phenylacetic acid) FeEDDHA (Sequestrin Fe-138, Ciba-Geigy) was applied manually to the trees. The trees were treated with systemic pesticides [Confidor (imidacloprid) soil application in May and Mospilan (acetamiprid) trunk application in August] to control citrus leaf-miner (*Phyllocnistis citrella*). Prophylactic fungicide treatment [metalaxyl+mancozeb (Ridomil MZ)] was applied to prevent possible phytophthora damage. No such damage was detected during the reported study.

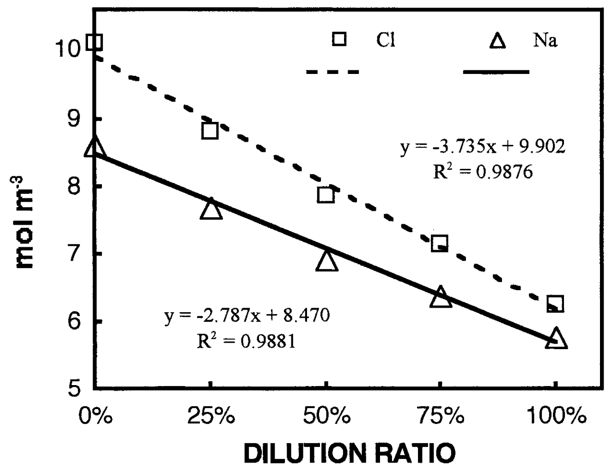


Fig. 3 The ion concentrations in the irrigation water along the dilution gradient

Leaf analysis

Twenty spring-flush leaves were collected from each tree at the end of September 1997 after irrigation for ~150 days. Leaves were washed in dilute detergent (Nonidet B.D.H.), and dried in a ventilated oven at 65 °C. Pulverized leaf (100 mg) was shaken for 4 h in 5 ml of water and Cl^-, Na K were determined in the supernatant as described before.

Results and discussion

Water collected in the orchard during each irrigation showed good linear correlations between the mean Cl^- and Na concentrations and the planned dilution ratio (Fig. 3).

Significant correlations were found between the applied waters and the concentrations of Cl^-, Na and K in the scion leaves of rootstock combination that responded to the salinity treatment.

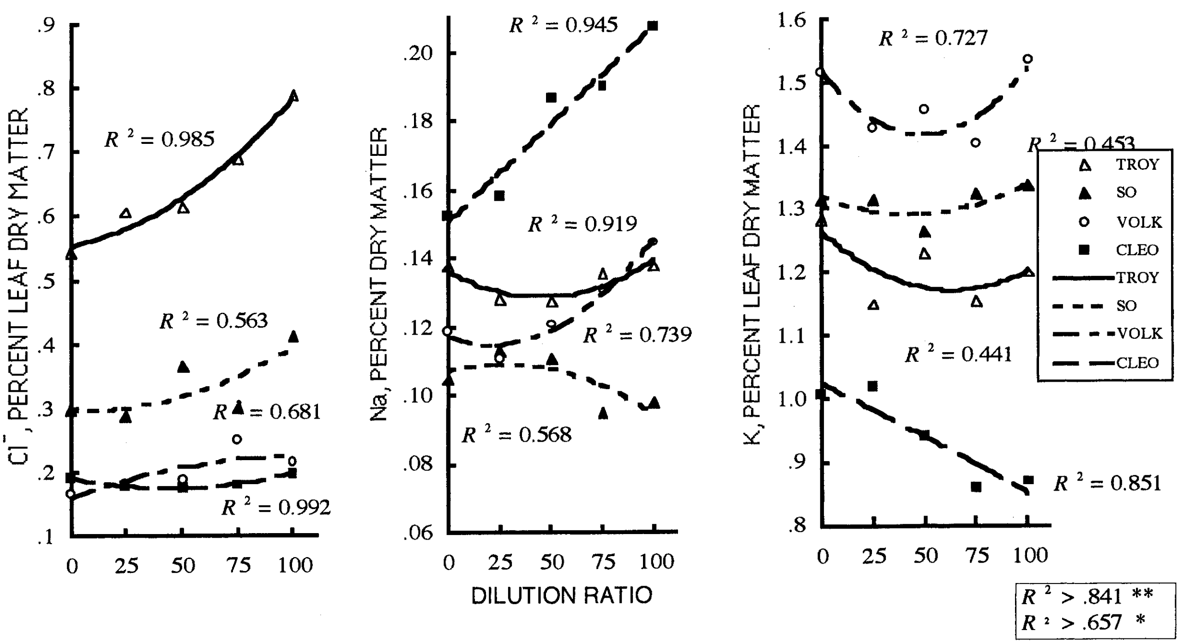
In Fig. 4 we present the concentration of Cl^-, Na and K in the leaves of grapefruit trees grafted on four different rootstocks. The results indicate that the method is sensitive enough to the determine the rootstock sensitivity to salinity, even after a short salinization period. The findings confirm previous observations that citrus scions grafted on Troyer citrange accumulate Cl^-, and that trees on Cleopatra mandarin exclude Cl^- but accumulate Na (Bañuls et al. 1997; Bar et al. 1997; Cerezo et al. 1997; Levy and Shalhevet 1990; Levy et al. 1992). The preliminary results suggest that Volkameriana, at least as a young tree, may be doing better than anticipated, whereas sour orange, which was tolerant to both Cl^- and Na accumulation as a mature tree (Levy and Shalhevet 1991), may not be so tolerant as a rootstock for young trees. These results also confirm observations that salinity can reduce K nutrition (Levy and Shalhevet 1991; Levy et al. 1992; Botella et al. 1997).

The above data are presented as an example of the results possible with the trickle linear gradient system, the effect of salinity on trees is cumulative and the final salinity thresholds of the different rootstocks will be evaluated in a long-term experiment.

Conclusions

The significant regression lines obtained between the dilution ratios and the accumulation of Cl^-, Na and K in the scion leaves of the different rootstock combinations prove

Fig. 4 Leaf ionic concentration along the dilution gradient (*SO* sour orange, *VOLK* Volkameriana, *CLEO* Cleopatra, *TROY* troyer)



that this method can easily be adapted to the study of a gradient of any soluble material administered through the irrigation system. The main improvement to this system over that used by De Malach et al. (1996) is the fact that the water is thoroughly mixed in a closed system and administered through a regular drip emitter, thus eliminating the chance that two separate streams of waters with different salinities reach the soil, with the roots following the lower salinity stream. At the same time the system is as robust as a commercial drip system and can function for many years in the field.

In the long run, the root systems of adjacent trees may become biased towards the lower salinity side of the trees. However, it is anticipated that the response will be similar at all salinities, and the response to salinity will remain linear.

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