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# Impact of salinity on macro- and micronutrient uptake in mango *(Mangifera indica* L. cv. Osteen) with different rootstocks

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## Abstract

Two mango (*Mangifera indica* L.) rootstocks Gomera-1 and Gomera-3, grafted with the scion Osteen, were irrigated at four different NaCl concentrations measured by electrical conductivity (1.02, 1.50, 2.00 and 2.50 dS $m^{-1}$). The aim was to determine the impact of salinity on macro- and micronutrient uptake. The nutrient imbalances from the effect of salinity on nutrient uptake, availability and partitioning within the plant resulted in less injurious with Gomera-1. Thus, the results corroborated the higher capability of Gomera-1 respect to Gomera-3 rootstocks to better adapt to saline conditions. The saline irrigation in leaves significantly raised the concentration of P, Ca, Fe, Zn and Mn, and lowered the Mg of both rootstocks, tending to decrease the N, and increase K and Cu. In the stem the values for N, Ca, Mg and Cu significantly augmented, whereas Zn tended to decrease. The root system registered a significant decrease of P, K and Mg and increase of N, Fe, Mn and Cu, while the fibrous root tended to concentrate most nutrients with more intensity than did the main root. With Gomera-1 the micronutrient concentrations in roots was higher than Gomera-3 in response to rising NaCl concentration.

**Key words:** mineral nutrition, salt stress, subtropical orchards

## Resumen

**Impacto de la salinidad en la absorción de macro y micronutrientes en mango *(Mangifera indica* L. cv. Osteen) con diferentes portainjertos**

Dos portainjertos de mango *(Mangifera indica* L.) Gomera-1 y Gomera-3, injertados con el cv. Osteen fueron sometidos a riego con cuatro concentraciones diferentes de NaCl, medidas por la conductividad eléctrica (1,02; 1,50; 2,00 y 2,50 dS $m^{-1}$). El objetivo fue determinar el impacto de la salinidad en la absorción de macro y micronutrientes. Los desequilibrios nutricionales provocados por el efecto de la salinidad en la absorción de nutrientes, disponibilidad y distribución en la planta resultaron menos perjudiciales con Gomera-1. Así, los resultados obtenidos corroboran la mayor capacidad del portainjerto Gomera-1 respecto de Gomera-3 para adaptarse a las condiciones salinas. El riego salino en ambos portainjertos incrementó significativamente la concentración foliar de P, Ca, Fe, Zn y Mn, redujo el Mg, y además se registró una tendencia al descenso de N y al incremento de K y Cu. En los tallos los valores para N, Ca, Mg y Cu se incrementaron significativamente, mientras el Zn tendió al descenso. El sistema radical registró un descenso significativo de P, K y Mg, y un incremento de N, Fe, Mn y Cu; además la raíz fibrosa tendió a concentrar la mayoría de nutrientes con más intensidad que la raíz principal. Con Gomera-1, en respuesta al ascenso de la concentración de NaCl, la concentración de micronutrientes en las raíces fue mayor que con Gomera-3.

**Palabras clave:** nutrición mineral, estrés salino, cultivos subtropicales.

## Introduction

On the coast of the provinces of Granada and Málaga (SE-Spain), subtropical fruit cultivation covers some 13,000 ha, some 8,500 being avocado (*Persea americana* Mill), 3,500 cherimoya (*Annona cherimolia* Mill) (Calatrava, 1998), and 800 ha of mango (*Mangifera indica* L.), a fruit in high demand in Europe and currently one of the crops with the greatest expansion (FAO-STAT, 2003).

Salinity from irrigation water, resulting from marine-water intrusion during dry years, causes severe damage —at times irreversible— particularly from the

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chloride in the water. The need for information concerning the tolerance and mineral nutrition of the mango rootstocks in the saline zones, and thus concerning the impact of salinity on fruit yield, has direct economic implications. In addition, mango is considered sensitive to saline conditions (Maas, 1986), leading to scorched leaf tips and margins, leaf curling, and in severe cases reduced growth, abscission of leaves, and death of trees (Jindal *et al*., 1976 a).

Preliminary studies under saline irrigation water revealed a trend of the capability of rootstock Gomera-1 to retain the $Cl^-$ and $Na^+$ among the plant organs: roots, stem and leaves. In addition, the rootstock Gomera-3 tended to take up a greater amount of $Cl^-$ and $Na^+$ than did Gomera-1, the latter proving more salt sensitive (Durán *et al*., 2003 a). Previously, Kadman *et al*. (1976) and Gazit and Kadman (1980, 1983) demonstrated tolerance to saline water in the rootstock 13/1, widely used in Israel; however, this rootstock is rare in our study zone, whereas the Canary Island rootstocks Gomera-1 and Gomera-3 are extensively cultivated (Galán and García, 1979; Galán and Fernández, 1987; 1988). The cultivars most commonly used in the zone, for their commercial appeal, include the Florida (USA) varieties: Osteen, Keitt, Tommy Atkins, Irwin, Sensation etc. (Galán, 1990, 1999).

Nevertheless, information regarding the rootstock effects on mineral nutrition of commercial mango cultivar under saline conditions in the zone is meagre (Martínez *et al*., 1999, Durán *et al*., 2002, Durán *et al*., 2003 b). The relationship between salinity and mineral nutrition of the plants is complex and still not very clear. It remains difficult to reconcile the results of salinity-nutrition experiments under field conditions, with those of greenhouse experiments; in soils that with nutritious solutions; using simple salts or a mixture of these or made studies over the short term, than over the long term. Many studies have reported macro and micronutrients uptake rates within plants, but the results did not always agree.

As mango orchards in Spain are grown under irrigation, mainly by drip systems, analyses are also needed concerning the mango rootstocks and the influence of salt on nutrient uptake. In the present work, we evaluated two mango rootstocks, Gomera-1 and Gomera-3, to high salinity. In addition, we studied the influence of these rootstocks on nutrient concentration, determining the balance and distribution of N, P, K, Ca, Mg, Fe, Zn, Mn and Cu in roots, stems and leaves of the rootstock and scion.

## Material and Methods

### Plant material and growth conditions

The study was conducted from July 1998 to April 1999, at the Experimental Station «El Zahorí» in Almuñecar (SE-Spain). A total of 48 4-year-old, similarly developed, juvenile mango trees of *Mangifera indica* L. cv. Osteen were grafted onto two rootstocks: Gomera-1 (G-1) and Gomera-3 (G-3). In these plants, leaves were left on the rootstocks. Each plant was planted in a plastic pot 38 cm in diameter and 40 cm in height, with sandy loamy soil (68.4, 23.5 and 8.1% of sand, silt and clay, respectively), containing 0.94% of organic matter, 0.07% of nitrogen, 17.6 of phosphorus and 165.7 mg $kg^{-1}$ assimilable potassium. The soil pH was 7.81, and the electrical conductivity (EC) (25ºC) of soil-saturation extract was 1.45 dS $m^{-1}$. The characteristics of the control water were: pH 7.74, EC of 1.02 dS $m^{-1}$, 272.0 mg $l^{-1}$ of $HCO_3^-$, 171.0 mg $l^{-1}$ $SO_4^{2-}$, 104.0 mg $l^{-1}$ $Cl^-$, 3.10 mg $l^{-1}$ $NO_3^-$, 49.0 mg $l^{-1}$ $Na^+$, 4.70 mg $l^{-1}$ $K^+$, 92.1 mg $l^{-1}$ $Ca^{2+}$, and 59.2 mg $l^{-1}$ $Mg^{2+}$. The adjusted sodium absorption ratio (Adj. SAR) was 2.33. The fertilizer-application rate per plant was 8.5 g N, 2.7 g $P_2O_5$ and 7.5 g $K_2O$.

Four irrigation treatments were applied, adding three increments of sodium chloride to the water available at the experimental station. The control water, relatively high in salinity, was used as representative of local irrigation (Table 1). Two Netafim self-regulating

**Table 1.** Electrical conductivity (EC) and composition of irrigation waters

| Irrigation water | NaCl added ($g\ l^{-1}$) | EC 25°C ($dS\ m^{-1}$) | Chloride ($mg\ l^{-1}$) | Sodium ($mg\ l^{-1}$) | Adj. SAR |
|---|---|---|---|---|---|
| A (control) | 0.00 | 1.02 | 104 | 49 | 2.33 |
| B | 0.28 | 1.50 | 280 | 156 | 7.44 |
| C | 0.51 | 2.00 | 425 | 250 | 11.8 |
| D | 0.82 | 2.50 | 588 | 375 | 17.2 |

Adj. SAR: adjusted sodium absorption ratio.

drip emitters per plant providing 4-l $h^{-1}$ applied the irrigation treatments. The 48 grafted plants were arranged in a completely randomized design including four salinity levels and two rootstocks with six replications per salinity-rootstock combination.

### Sampling and mineral analyses

At the end of the experiment, the concentrations of macro- and micronutrients in the various plant organs were measured by taking samples from both the Gomera-1 and Gomera-3: cultivar (scion Osteen) leaves (CL), cultivar stem (CS; including branches), rootstock leaves G-1 and G-3 (RL), rootstock stem (RS), main root (MR) and fibrous roots (FR) (Fig. 1). In addition, throughout the ten study months, foliar (CL) measurements were taken from grafted plants at 10 days after the beginning (I), 110 (II), 210 (III) and 300 (IV) days, respectively. Before analysis, all samples were washed thoroughly with distilled water, dried at 70°C for 48 h to constant weight and then ground.

Mineral analyses were performed on uniform subsamples of the oven-dried tissues. The amount of N present in tissues was determined by the Kjeldahl method (Bremner, 1965); P was measured by the molybdenum-blue method (Fiske, 1925). Determinations for K, Ca, Mg, Fe, Zn, Mn and Cu were by atomic-absorption spectrophotometry (Chapman and Pratt, 1961)

### Statistical analysis

The experimental results were submitted to an analysis of variance ANOVA. Differences among macro- and micronutrients were determined by Fisher's LDS test at a significance level of 0.05. All statistical analyses were conducted using Statgraphics 4.1 program

## Results and Discussion

The salt treatments were applied for 10 months until some mango plants of treatment D (2.5 dS $m^{-1}$) showed severe defoliation due to chloride burn. Total leaf drop followed by plant death and the onset of a generalized behaviour in the other plants prompted us to suspend irrigation and evaluate the effects of the salt toxicity. The percentage of burned leaves of mango cv. Osteen (CL) grown on the G-3 rootstock was significantly higher than when grown on the G-1. The preliminary visual symptoms of the G-1 rootstock indicated a relative tolerance to NaCl in irrigation waters (Durán *et al*., 2003 a). A linear decline in dry matter correlated with rising levels of salinization in agreement with Galán *et al.* (1989), and with other findings such as *Persea americana* Mill (Weisman, 1995; Bernstein *et al*., 2001), *Pyrus betulifolia* Bunge and *Pyrus pyrifolia* Burm F. (Okubo *et al.*, 2000).

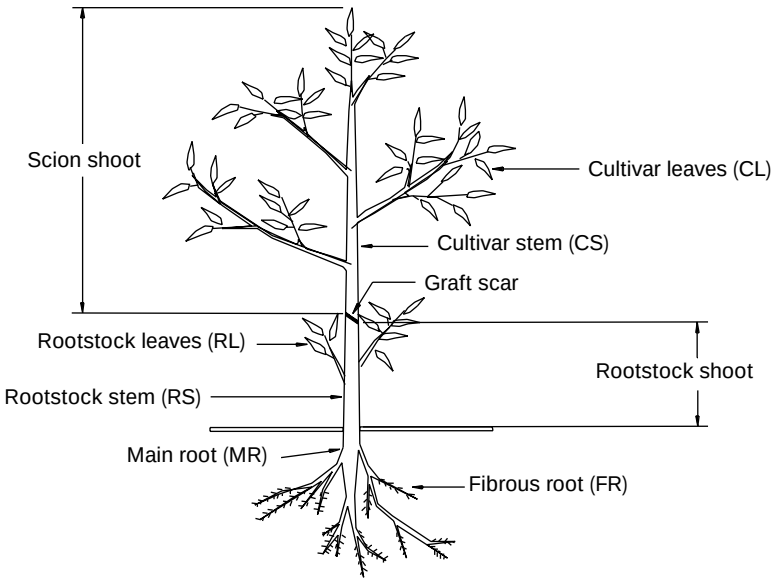


**Figure 1.** The partitioning of mango plants at harvest.

## Macronutrients

The two rootstocks differed significantly in macronutrient concentrations (as mg $g^{-1}$) in all saline treatments, except for N and K in leaves, for G-1 rootstock plants N and Ca in stem, and Ca in root. The G-3 rootstock did not differ significantly for P and K in stem (Table 2). Meanwhile, the N concentration between the cultivar and rootstock tissues in leaves and stem did not significantly differ. In the experiment, the N concentration tended to increase with salinity in stem and root, and decrease in leaves. Increased $Cl^-$ uptake and accumulation is often accompanied by decreased shoot N-$NO_3$ concentrations. Examples of such an effect have been found in *Cucumis sativus* L., *Lycopersicon esculentum* L. (Martínez and Cerda, 1989) and *Solanum melongena* L. (Savas and Lenz, 1996). Some authors have attributed this reduction to $Cl^-$ antagonism against N-$NO_3$ uptake (Bar *et al*., 1997), while others cite reduced water uptake due to salinity (Lea-Cox and Syvertsen, 1993), although some studies report less effect or even the opposite (Feign, 1985). The results of salinity and N-source studies conducted in hydroponic or sand cultures contrast markedly with studies where plants were grown in soil, such as our experiment. In addition, we found that salinity increased the N concentration in the root but decreased the K concentrations, as in studies on *Citrus* species (García *et al.*, 2002 a).

The P levels in leaves registered a few changes with increasing saline treatments, especially in G-1. Likewise, intermediate salinity levels B and C reduced the P concentrations in the stem. Under salinity the P concentration of cultivar leaves was higher than in rootstock leaves, but with the stem the concentration was higher in rootstock tissues (RS). In both the stem and root of G-3, the P concentration in all treatments was higher than in G-1. This fact could in the future directly influence the vigour of G-3 trees and consequently the foliar level of the grafted scion. In this sense, Eswara *et al*. (1983) reported that stem and branches of mango trees are sink organs for nutrients, especially of P.

Bañuls *et al*. (1990), studying citrus under salinity conditions, reported little change in the P concentration but lower the N contents both in leaves and in the roots. Similarly in our experiment, the N concentrations fell in leaves but not in roots, while the P rose in leaves and fell in the roots, according with Ruiz *et al*. (1997). In most cases, salinity decreases the P concentration in plant tissue (Sharpley *et al*., 1992), but some studies indicate no effect or even that salinity boosts P uptake; however, higher tissue-P concentrations correspond to experiments in sand or solution cultures, not soils (Grattan and Grieve, 1994). It is not surprising that differences among studies occur, since P concentrations vary widely in different experiments, and other nutrient interactions could be occurring simultaneously.

The K concentration in control leaves changed little with respect to the strongest saline treatment D of both rootstocks, but more intensely in B and C treatments, as in other studies such as García-Lidon *et al*. (1998) studying rootstocks-scion combinations in lemon trees subjected to salinity. In addition, Walker (1986) attributed leaf-K increases in some rootstock-scion combinations to an exchange between Na and K in the basal stem and proximal root whereby K was released from the root to the xylem for transport to the leaf.

In our study, the K level in most organs of control and salinized plants of G-1 were higher than for G-3, in agreement with Schnabl (1980), who noted that the K presence especially in leaves buffers against $Cl^-$ damage. The K concentration rose in the stem with G-1 plants and fell with G-3. The salinity in the present study decreased the K concentration in the roots, suggesting an exchange of K with Na ions. The reduction in K uptake caused by Na is a well-know competitive process in plant roots (Cerda *et al.*, 1995). Ruiz *et al*. (1997) and García *et al*. (2002 b), studying the uptake and transport of K in citrus rootstocks found similar behaviour, and Chirachint and Turner (1988) reported analogous findings for *Persea americana* Mill. Under saline conditions, high levels of external Na not only interfere with K uptake by the roots, but also may disrupt the integrity of root membranes and alter their selectivity.

In both rootstocks the Ca level in the leaves and stem in salinized plants was higher than in control, and the presence in rootstock tissues (RS) differed significantly with respect to the cultivar (CS). In the root system the Ca concentration tended to increase, being higher in fibrous roots than in the main root. In general, the Ca concentration of rootstocks tissues was higher than in the cultivar. Despite the low mobility of Ca in the interior of the plant, highest concentrations are found in older leaves (rootstocks tissues) and increase with age (Mills and Benton, 1996).

In the present experiment, under salinity conditions the root system increased the Ca concentration by 2.7

**Table 2.** Tissue macronutrient content (mg $g^{-1}$ dry wt) and LSD test grouping

| | **Means and LSD distributions** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Gomera-1 rootstock** | | | | | **Gomera-3 rootstock** | | | | |
| | **N** | **P** | **K** | **Ca** | **Mg** | **N** | **P** | **K** | **Ca** | **Mg** |
| **LEAF** | | | | | | | | | | |
| *IW* | | | | | | | | | | |
| — A | 15.1a | 0.7a | 3.3a | 21.5a | 2.5a | 16.1a | 0.8a | 2.8a | 14.7a | 2.3a |
| — B | 14.6a | 0.9a | 4.3a | 21.1a | 1.8b | 14.7a | 1.1b | 4.0a | 17.6ab | 1.6b |
| — C | 14.9a | 1.0a | 3.8a | 25.2ab | 2.1b | 14.6a | 1.0b | 3.2a | 21.3c | 1.7bc |
| — D | 13.5a | 0.9a | 3.8a | 28.6b | 1.0b | 14.4a | 1.0b | 3.2a | 19.8bc | 0.9c |
| *Tissue* | | | | | | | | | | |
| — CL | 14.1a | 1.0a | 4.1a | 18.9a | 1.7a | 14.8a | 1.1a | 3.2a | 18.6a | 1.9a |
| — RL | 14.5a | 0.7a | 3.5a | 29.2b | 1.9a | 15.3a | 0.9b | 3.1a | 18.8a | 1.4b |
| *ANOVA* | | | | | | | | | | |
| — IW | NS | NS | NS | NS | * | NS | * | NS | * | * |
| — Tissue | NS | NS | NS | * | NS | NS | * | NS | NS | * |
| — IW-Tissue | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| **STEM** | | | | | | | | | | |
| *IW* | | | | | | | | | | |
| — A | 6.8a | 1.3a | 5.5a | 20.0a | 2.8a | 5.0a | 2.0a | 5.6a | 20.9a | 2.4a |
| — B | 7.1a | 0.7c | 5.0a | 21.2a | 2.3a | 6.3b | 1.9a | 5.9a | 26.7b | 3.0ab |
| — C | 8.2a | 0.9bc | 6.7b | 21.0a | 2.8a | 7.9c | 1.9a | 4.8a | 25.1b | 4.7bc |
| — D | 9.8a | 1.0ab | 5.9ab | 23.4a | 3.8b | 8.5c | 2.0a | 4.6a | 27.1b | 4.2c |
| *Tissue* | | | | | | | | | | |
| — CS | 8.0a | 0.8a | 6.6a | 14.8a | 1.6a | 6.0a | 1.8a | 5.5a | 19.1a | 2.2a |
| — RS | 8.2a | 1.2a | 5.0b | 28.0b | 4.2b | 7.9b | 2.1a | 5.0a | 30.8b | 4.9b |
| *ANOVA* | | | | | | | | | | |
| — IW | NS | NS | NS | NS | * | * | NS | NS | * | * |
| — Tissue | NS | NS | * | * | * | * | NS | NS | * | * |
| — IW-Tissue | NS | NS | NS | NS | NS | NS | NS | NS | * | * |
| **ROOT** | | | | | | | | | | |
| *IW* | | | | | | | | | | |
| — A | 9.0a | 0.7a | 5.0a | 9.0a | 2.9a | 8.0a | 0.9a | 4.9a | 11.7a | 3.2a |
| — B | 9.1a | 0.6b | 4.3b | 12.1a | 2.5b | 9.4b | 0.6b | 4.4ab | 16.8b | 2.8a |
| — C | 9.8ab | 0.5b | 4.8ab | 13.4a | 2.4b | 10.3bc | 0.5b | 4.1ab | 14.2ab | 2.8a |
| — D | 11.2b | 0.6ab | 3.8c | 11.7a | 2.2b | 11.0c | 0.7ab | 3.7b | 12.3a | 2.1b |
| *Tissue* | | | | | | | | | | |
| — MR | 8.5a | 0.6a | 4.4a | 10.4a | 2.3a | 8.8a | 0.7a | 4.1a | 10.8a | 2.5a |
| — FR | 11.0b | 0.6a | 4.7a | 12.7a | 2.7b | 10.6b | 0.7a | 4.5a | 16.7b | 3.0b |
| *ANOVA* | | | | | | | | | | |
| — IW | NS | * | * | NS | * | * | * | NS | * | * |
| — Tissue | * | NS | NS | NS | * | * | NS | NS | * | * |
| — IW-Tissue | NS | NS | NS | NS | NS | NS | NS | NS | * | NS |

Means followed by the same letter in each column are not significantly different at level 0.05. NS: not significant. * Significant at level 0.05. IW: irrigation water. CL: cultivar leaf. RL: rootstock leaf. CS: cultivar stem. RS: rootstock stem. MR and FR: main and fibrous root of rootstocks.

(mg $g^{-1}$) in G-1, and by only 0.6 in G-3, from control to the D treatment. This situation is noteworthy, because Ca during the salt stress helps preserve membrane integrity (Rengel, 1992). Azaizeh *et al*. (1992) and Neumann *et al*. (1994) reported that the Ca maintains root hydraulic conductivity, thereby mitigating foliar injury and defoliation (Zekri and Parsons, 1992; Bañuls *et al*., 1997). In addition, Kent and Laüchi (1985) found that a high Ca concentration in the root ameliorates the negative effect of salinity on root growth and function. In our experiment the higher increase of Ca concentration in the root system of G-1 plants under salinity was resulting in less $Cl^-$ damage than with G-3 (Durán *et al*., 2003 a).

Under salinity in both rootstocks, the Mg levels fell in leaf and roots but rose in the stem. In this sense, Jindal *et al*. (1976 b) found that $Na_2SO_4$ reduced the uptake of Mg and P and caused deficiency symptoms in leaves of salinized plants, similarly in the present experiment the Mg content in leaves and roots fell, but by contrast the P rose in leaves and fell in roots. In addition, Ruiz *et al.* (1997) reported that NaCl reduced the Mg concentration in citrus leaves. However, Bernstein *et al.* (1974) found that stronger salinity lowered the leaf-Mg concentration in *Beta vulgaris* L. and had little or no effect in five other vegetable crops. In addition, Bernstein and Hayward (1958) reported that leaf-Ca rose with lower leaf Mg, as occurred in our mango experiment. Also, Ca is strongly competitive with Mg, and the binding sites on the root plasma membrane appear to have less affinity for highly hydrated Mg than for Ca (Marschner, 1995). A pattern similar to that of stem Ca was found for stem-Mg levels, which increased under salinity. The Mg accumulated more in the rootstock stem than in the cultivar stem and its level in the present experiment was higher in G-3 plants than G-1.

The root system of G-1 tended to increase more in N and Ca, or decrease less in P and Mg concentrations from control to D treatment in comparison to the G-3. Ben Ya'acov (1970) and Díaz *et al*. (1984), working with *Persea americana* Mill under salinity conditions, reported a trend to increase or remain stable the concentrations of the principal macronutrients in the root system, and this phenomenon was considered a tolerance index.

## Micronutrients

The analysis of variance revealed a significant difference between the control A and strongest saline treatment D in G-1 plants for Fe, Zn and Mn in leaf, Zn and Cu in stem, and Fe, Zn, Mn and Cu in root, as well as in G-3 for Mn and Cu in leaf, Zn and Mn in stem, and Mn and Cu in root (as μg $g^{-1}$ dry weight) (Table 3).

In both rootstocks, the Fe in the leaves, stem and roots tended to increase with salinity. The Fe concentration in both G-1 and G-3 followed the sequence root > stem > leaf, with higher values in rootstock organs than in the cultivar.

Under salinity, the Zn concentration diminished in the stem and roots, especially with G-1 plants, while the trend to increase in the leaf was similar for both rootstocks. As with Fe, Zn was found in the roots in higher proportions than in the stem or leaves, and at higher levels in cultivar leaf and stem tissues (CL-CS) than in rootstock (RL-RS), especially with G-1.

Meanwhile, the Mn concentration of both rootstocks followed the sequence leaf > root > stem, particularly with G-3. In the strongest saline treatment D, the Mn levels in leaf and root tissues sharply increased. The Mn concentration in cultivar stem was higher than in the rootstock. Finally, the Mn presence in stem and root of G-1 in control or salinized plants was greater than in G-3.

As with Fe, Zn and Mn, the Cu concentration tended to increase in all organ tissues under saline conditions. Significant differences of Cu concentration in stem (CS and RS) and roots (FR and MR) were found, and in the D saline treatment, the Cu levels in these tissues increased notably with respect to control plants.

In saline and sodic soils, the solubility of micronutrients (Fe, Zn, Mn, and Cu) is particularly low, and plants grown in these soils often develop deficiencies in these elements (Page *et al*., 1990). Differences can be attributed to plant type, plant tissue, salinity level, growing conditions and the duration of the study. Thus, salinity stress stimulates as well as inhibits the uptake of some micronutrients by crop plants. According to Villora *et al*. (2000), the foliar concentrations of Fe, Zn and Mn increase in response to rising NaCl levels, this is consistent with Alam (1994) who reported high uptake of these micronutrients in addition to Cu. In our experiment with mango, we found a similar tendency of increased concentrations of all micronutrients, with exception the Zn in the stem.

The Fe-shoot concentration of mango plants under salinity conditions tended to increase, according with findings of Maas *et al*. (1972), Dahiya and Sing (1976) and Verma and Neue (1984) studying diverse vegetal species. In the present work we found a general increase of Mn in all organ tissues of mango plants with ex-

**Table 3.** Tissue micronutrient content (μg $g^{-1}$) dry wt) and LSD test grouping

| | **Means and LSD distributions** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Gomera-1 rootstock** | | | | **Gomera-3 rootstock** | | | |
| | **Fe** | **Zn** | **Mn** | **Cu** | **Fe** | **Zn** | **Mn** | **Cu** |
| **LEAF** | | | | | | | | |
| *IW* | | | | | | | | |
| — A | 59.5a | 15.0a | 38.0a | 28.0a | 74.0a | 20.7a | 173.5a | 30.7ab |
| — B | 69.7ab | 18.0ab | 49.5ab | 27.0a | 82.7a | 18.7a | 180.5a | 39.0b |
| — C | 61.5a | 19.0b | 57.7b | 33.0a | 78.0a | 19.7a | 138.2a | 40.2b |
| — D | 80.5b | 20.0b | 139.7c | 37.2a | 88.5a | 22.5a | 265.2b | 27.2a |
| *Tissue* | | | | | | | | |
| — CL | 51.7a | 18.7a | 65.8a | 36.1a | 67.1a | 20.6a | 181.0a | 34.3a |
| — RL | 83.8b | 17.2a | 76.6a | 26.5a | 94.5a | 20.7a | 197.6a | 34.2a |
| *ANOVA* | | | | | | | | |
| — IW | NS | NS | * | NS | NS | NS | * | NS |
| — Tissue | * | NS | NS | NS | NS | NS | NS | NS |
| — IW-Tissue | NS | * | * | * | NS | * | NS | NS |
| **STEM** | | | | | | | | |
| *IW* | | | | | | | | |
| — A | 105.0a | 26.7a | 39.7a | 24.7a | 98.0a | 26.0a | 17.5a | 29.7a |
| — B | 113.7a | 15.2b | 32.5a | 20.2a | 116.2a | 15.0b | 20.2a | 28.7a |
| — C | 160.5a | 23.5ab | 27.0a | 39.0b | 152.7a | 17.0b | 25.0b | 31.0a |
| — D | 161.7a | 19.5ab | 40.0a | 41.5b | 166.7a | 14.2b | 11.5c | 41.5a |
| *Tissue* | | | | | | | | |
| — CS | 54.0a | 27.3a | 39.5a | 17.8a | 68.2a | 19.3a | 26.6a | 22.3a |
| — RS | 216.5b | 15.1b | 30.0a | 44.8b | 198.6b | 16.8a | 10.5b | 43.1b |
| *ANOVA* | | | | | | | | |
| — IW | NS | NS | NS | * | NS | * | * | NS |
| — Tissue | * | * | NS | * | * | NS | * | * |
| — IW-Tissue | NS | NS | NS | NS | NS | NS | * | NS |
| **ROOT** | | | | | | | | |
| *IW* | | | | | | | | |
| — A | 151.0a | 36.5a | 73.0a | 25.0a | 153.2a | 21.0a | 53.5a | 25.5a |
| — B | 202.7ab | 28.2b | 83.0a | 30.2ab | 185.7a | 21.7a | 58.7ab | 28.0a |
| — C | 153.5ab | 29.2ab | 74.7a | 40.0b | 149.7a | 20.2a | 58.7ab | 41.0ab |
| — D | 224.0b | 26.5b | 149.0b | 59.7c | 189.7a | 23.0a | 101.2b | 54.7b |
| *Tissue* | | | | | | | | |
| — MR | 88.3a | 16.8a | 88.7a | 23.1a | 130.2a | 12.3a | 51.7a | 27.8a |
| — FR | 277.2b | 43.3b | 101.1a | 54.3b | 209.0b | 30.6b | 84.3b | 46.7b |
| *ANOVA* | | | | | | | | |
| — IW | NS | NS | * | * | NS | NS | NS | * |
| — Tissue | * | * | NS | * | * | * | * | * |
| — IW-Tissue | NS | NS | NS | NS | NS | NS | NS | NS |

Means followed by the same letter in each column are not significantly different at level 0.05. NS: not significant. * Significant at level 0.05. IW: irrigation water. CL: cultivar leaf. RL: rootstock leaf. CS: cultivar stem. RS: rootstock stem. MR and FR: main and fibrous root of rootstocks.

**Table 4.** Macronutrient content in cv. Osteen leaves over the time

| EC/date sampling | N (mg g$^{-1}$) | | P (mg g$^{-1}$) | | K (mg g$^{-1}$) | | Ca (mg g$^{-1}$) | | Mg (mg g$^{-1}$) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | G-1 | G-3 | G-1 | G-3 | G-1 | G-3 | G-1 | G-3 | G-1 | G-3 |
| **A** | | | | | | | | | | |
| I | 14.5 (0.21) | 16.5 (0.15) | 0.7 (0.01) | 0.9 (0.03) | 3.3 (0.15) | 2.9 (0.12) | 21.7 (0.51) | 14.7 (0.20) | 2.4 (0.36) | 2.4 (0.35) |
| II | 14.8 (0.17) | 16.4 (0.10) | 0.8 (0.01) | 0.8 (0.03) | 3.5 (0.26) | 3.0 (0.15) | 22.2 (0.60) | 15.0 (0.50) | 2.5 (0.05) | 2.4 (0.35) |
| III | 15.1 (0.06) | 16.7 (0.20) | 0.8 (0.02) | 0.8 (0.02) | 3.7 (0.21) | 3.3 (0.25) | 22.0 (0.45) | 15.4 (0.40) | 2.5 (0.16) | 2.5 (0.23) |
| IV | 15.8 (0.15) | 17.1 (0.06) | 0.9 (0.01) | 1.0 (0.02) | 3.8 (0.25) | 3.3 (0.21) | 22.5 (0.15) | 15.8 (0.32) | 2.6 (0.20) | 2.6 (0.15) |
| **B** | | | | | | | | | | |
| I | 14.6 (0.06) | 16.1 (0.06) | 0.7 (0.02) | 0.9 (0.02) | 3.4 (0.25) | 3.0 (0.40) | 21.8 (0.55) | 15.0 (0.81) | 2.5 (0.06) | 2.4 (0.14) |
| II | 14.4 (0.21) | 15.8 (0.15) | 0.8 (0.01) | 0.8 (0.02) | 3.7 (0.20) | 3.4 (0.31) | 22.6 (0.60) | 15.9 (0.64) | 2.4 (0.40) | 2.1 (0.12) |
| III | 14.1 (0.16) | 15.3 (0.31) | 0.9 (0.02) | 0.9 (0.01) | 3.8 (0.06) | 3.5 (0.25) | 22.8 (0.06) | 17.0 (0.45) | 2.3 (0.31) | 1.9 (0.23) |
| IV | 13.9 (0.12) | 15.1 (0.10) | 1.0 (0.02) | 1.0 (0.02) | 3.8 (0.15) | 3.5 (0.26) | 23.0 (0.35) | 18.0 (0.50) | 2.6 (0.40) | 1.7 (0.35) |
| **C** | | | | | | | | | | |
| I | 14.6 (0.06) | 16.3 (0.06) | 0.7 (0.01) | 0.9 (0.01) | 3.4 (0.15) | 3.0 (0.10) | 21.5 (0.50) | 14.9 (0.10) | 2.5 (0.36) | 2.4 (0.25) |
| II | 14.3 (0.21) | 15.5 (0.15) | 0.9 (0.02) | 0.9 (0.02) | 3.7 (0.17) | 3.2 (0.15) | 23.8 (0.25) | 15.8 (0.40) | 2.2 (0.26) | 1.9 (0.10) |
| III | 14.0 (0.25) | 14.7 (0.23) | 0.9 (0.01) | 0.9 (0.01) | 3.9 (0.32) | 3.3 (0.25) | 24.9 (0.15) | 19.0 (0.50) | 1.8 (0.26) | 1.7 (0.15) |
| IV | 13.4 (0.20) | 14.2 (0.15) | 1.1 (0.01) | 1.3 (0.02) | 4.0 (0.15) | 3.6 (0.10) | 26.0 (0.20) | 22.5 (0.50) | 1.5 (0.35) | 1.5 (0.36) |
| **D** | | | | | | | | | | |
| I | 14.5 (0.17) | 16.4 (0.10) | 0.8 (0.02) | 0.9 (0.01) | 3.4 (0.10) | 2.9 (0.15) | 21.6 (0.67) | 15.1 (0.12) | 2.4 (0.10) | 2.3 (0.23) |
| II | 14.0 (0.15) | 15.0 (0.31) | 0.8 (0.01) | 0.8 (0.02) | 3.8 (0.10) | 3.4 (0.10) | 23.5 (0.21) | 17.0 (0.50) | 2.0 (0.20) | 1.6 (0.15) |
| III | 13.7 (0.25) | 13.7 (0.20) | 0.9 (0.02) | 1.0 (0.01) | 4.0 (0.15) | 3.5 (0.15) | 27.5 (0.26) | 23.0 (0.55) | 1.5 (0.30) | 1.2 (0.10) |
| IV | 13.0 (0.12) | 13.4 (0.25) | 1.3 (0.02) | 1.4 (0.01) | 4.2 (0.25) | 3.8 (0.21) | 28.9 (0.50) | 24.0 (0.06) | 1.0 (0.15) | 0.8 (0.06) |

I: 10 days. II: 110 days. III: 210 days and IV: 300 days. Values in brackets are standard deviations.

ception in D treatment for stem of G-3 rootstock. Similarly Hassan *et al*. (1970 a, b) reported that salinity also increased the Mn concentration with *Hordeum vulgare* L. and *Zea mays* L.

In general, salinity tended to elevate the Cu concentration in the mango tissues. In contrast, leaf and shoot Cu concentrations were found to decrease in *Zea mays* L. grown both in soil (Ranham *et al*., 1993) and in solution cultures (Izzo *et al*., 1991), but NaCl salinity substantially increased leaf Cu in hydroponically grown *Lycopersicon esculentum* L. The influence of salinity on Cu concentration also varied.

Our early observations in a comparable experiment with mango trees under field conditions revealed no visual symptoms of micronutrient deficiency in the foliar mass, even under the strongest saline

**Table 5.** Micronutrient content in cv. Osteen leaves (CL) over the time

| EC/date sampling | Fe (µg g$^{-1}$) | | Zn (µg g$^{-1}$) | | Mn (µg g$^{-1}$) | | Cu (µg g$^{-1}$) | |
|---|---|---|---|---|---|---|---|---|
| | G-1 | G-3 | G-1 | G-3 | G-1 | G-3 | G-1 | G-3 |
| **A** | | | | | | | | |
| I | 60 (5.0) | 76 (9.8) | 15 (5.0) | 20 (3.0) | 38 (6.6) | 170 (17.2) | 27 (2.5) | 30 (9.2) |
| II | 59 (4.6) | 77 (12.5) | 16 (3.2) | 21 (2.9) | 40 (10.0) | 175 (27.2) | 25 (5.0) | 29 (2.5) |
| III | 60 (10.0) | 79 (1.0) | 15 (2.3) | 20 (3.1) | 39 (4.5) | 178 (10.1) | 27 (4.0) | 30 (10.1) |
| IV | 66 (4.0) | 81 (7.0) | 15 (2.3) | 21 (2.1) | 41 (6.1) | 180 (2.5) | 31 (10.0) | 35 (8.0) |
| **B** | | | | | | | | |
| I | 61 (6.0) | 74 (5.6) | 15 (1.0) | 19 (2.6) | 39 (4.0) | 168 (10.1) | 28 (4.2) | 31 (2.3) |
| II | 70 (6.8) | 77 (7.5) | 16 (3.2) | 20 (2.6) | 42 (9.8) | 170 (20.0) | 30 (7.2) | 38 (5.6) |
| III | 68 (7.6) | 80 (8.5) | 17 (3.6) | 17 (2.1) | 50 (9.0) | 175 (3.8) | 28 (2.6) | 40 (4.4) |
| IV | 78 (11.0) | 84 (8.1) | 17 (2.9) | 19 (3.1) | 55 (7.1) | 189 (11.0) | 35 (9.1) | 42 (3.1) |
| **C** | | | | | | | | |
| I | 60 (6.2) | 75 (9.3) | 15 (1.0) | 20 (2.5) | 40 (10.0) | 160 (9.1) | 27 (4.0) | 30 (7.8) |
| II | 63 (8.7) | 76 (10.7) | 15 (1.5) | 19 (5.5) | 50 (4.0) | 165 (10.0) | 28 (2.0) | 34 (7.0) |
| III | 65 (3.8) | 84 (5.0) | 16 (1.7) | 19 (1.0) | 55 (11.0) | 170 (17.6) | 35 (3.1) | 35 (6.0) |
| IV | 70 (5.8) | 89 (4.0) | 19 (1.7) | 23 (1.5) | 73 (8.1) | 168 (6.0) | 38 (5.9) | 43 (4.2) |
| **D** | | | | | | | | |
| I | 62 (10.4) | 76 (11.6) | 15 (1.0) | 20 (1.0) | 39 (8.1) | 175 (12.0) | 27 (6.1) | 29 (5.0) |
| II | 70 (12.4) | 79 (12.5) | 15 (0.6) | 20 (2.1) | 65 (11.4) | 198 (9.7) | 30 (6.1) | 30 (4.0) |
| III | 81 (8.0) | 85 (7.0) | 17 (1.7) | 21 (2.6) | 100 (10.5) | 250 (4.5) | 37 (6.7) | 37 (4.9) |
| IV | 86 (12.2) | 94 (11.0) | 21 (4.5) | 24 (2.6) | 140 (11.7) | 289 (9.5) | 40 (4.4) | 45 (5.9) |

I: 10 days. II: 110 days. III: 210 days and IV: 300 days. Values in brackets are standard deviations.

treatment D (Durán *et al*., 2003 b). This suggests that the saline irrigation water with EC ≥ 2.50 dS m$^{-1}$ does not notably lower the micronutrient concentration of the leaves.

Finally, fibrous roots were characterized by a greater concentration of macro- and micronutrients than in the main root. In addition, the foliar levels of nutrients (N, P, K, Fe, Zn, Mn and Cu) in 4-year-old mango juvenile trees, due the effect of the rootstock, were greater with G-3 plants. Similarly trend with trees cv. Osteen grafted on G-3 in full fruit production showed higher foliar levels in Cl and Na than did trees with G-1 (Durán *et al.*, 2003 b). In addition, a two-year field study with mango trees cv. Keitt grafted on G-3 demonstrated the capability of this rootstock to take up nutrients more readily (Durán *et al*., 2002).

**Table 6.** Salinity effect in nutrient concentration for individual organ tissues

| Element | Leaf | | Stem | | Root | |
|---|---|---|---|---|---|---|
| | G-1 | G-3 | G-1 | G-3 | G-1 | G-3 |
| N | (–) | (–) | (+) | (+) | (+) | (+) |
| P | (+) | (+) | (–) | (0) | (–) | (–) |
| K | (+) | (+) | (+) | (–) | (–) | (–) |
| Ca | (+) | (+) | (+) | (+) | (+) | (+) |
| Mg | (–) | (–) | (+) | (+) | (–) | (–) |
| Fe | (+) | (+) | (+) | (+) | (+) | (+) |
| Zn | (+) | (+) | (–) | (–) | (–) | (+) |
| Mn | (+) | (+) | (+) | (–) | (+) | (+) |
| Cu | (+) | (+) | (+) | (+) | (+) | (+) |

(+): increase. (–): decrease. (0): without change.

In general, during the experiment in all saline treatments (B, C and D) the cultivar leaves (CL) raised the contents of P, K and Ca, lowered the N and Mg of both combinations G1-Osteen and G3-Osteen (Table 4). In relation to micronutrients, the Fe, Zn, Mn and Cu contents augmented in response to salinity (Table 5). Table 6 summarizes the effect of increasing the NaCl concentration in irrigation waters on macro- and micronutrient uptake in organs, due the influence of different mango rootstocks.

## Fractional distribution of nutrients in plant organs

Figure 2 divides the accumulation of macro- and micronutrients in the scion shoot (SS) (cultivar shoot), as well as in the rootstocks shoot (RS) and rootstock root (RR), presented as a percentage contribution in each plant component to the total ion content. This division refers only to the scion-rootstock combinations growing in the control A and D treatments, as the other treatments follow similar patterns.

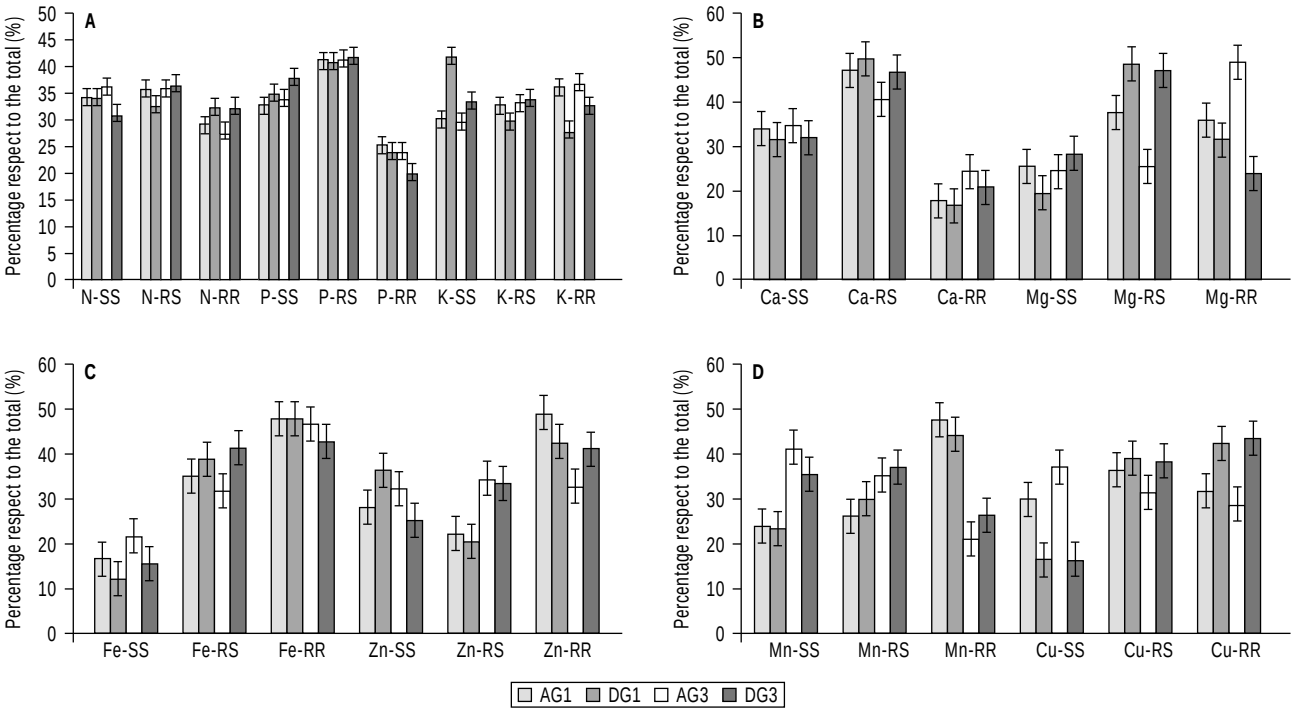


**Figure 2.** N-P-K (A), Ca-Mg (B), Fe-Zn (C) and Mn-Cu (D) content in shoots and root system with fractional contribution of each to the total content. SS: scion shoot. RS: rootstock shoot. RR: rootstock root. AG-1: 1.02 dS $m^{-1}$ (control) Gomera-1. DG-1: 2.5 dS $m^{-1}$ Gomera-1. AG-3: 1.02 dS $m^{-1}$ (control) Gomera-3. DG-3: 2.5 dS $m^{-1}$ Gomera-3. Vertical bars represent SE of the means, n = 6.

The data suggest for both G-1 and G-3 rootstocks that most of macro- and micronutrient accumulation operated similarly in salinized and control plants. However, with G-1 the P, K and Zn accumulation decreased in rootstock shoot, and increased in these elements in scion shoot (leaf and stem of cv. Osteen) in response to rising the electrical conductivity of irrigation waters. In this sense, Mehrotra *et al*. (1986) reported reduction of the shoot-Zn concentrations in *Zea mays* L., and Patel *et al*. (1976) in experiments with *Persea americana* Mill. noted the loss of Zn concentration in the organs, as well as increased levels of Ca, Mg, K, Fe and Mn, our mango experiment registered similar results. In addition, Anac *et al*. (1997) with mandarin trees found that K significantly increased leaf expansion and growth depression by salinity was less injurious, such as resulted in the present experiment with Gomera-1. Similar trends were identified with Mg to decrease in scion shoot and remain stable for Ca and Fe in rootstock roots.

Thus, on the basis of our experimental results, we conclude that the nutrient imbalances result from the effect of salinity on nutrient uptake, availability and partitioning within the plant resulted in less injurious with Gomera-1. These results corroborated the properties that the mango rootstock Gomera-1 can be used to improve the response of mango and related genera to salt stress (Durán *et al*., 2003 a).

For both rootstocks, the mango leaves with salinity significantly increased the levels of P, Ca, Fe, Zn and Mn, but reduced the Mg level, tending to decrease the N, and increase K and Cu concentrations. In the stem the N, Ca, Mg and Cu increased while the Zn decreased. Under salinity conditions the root system of both rootstocks significantly decreased in P, K and Mg, and increased in N, Fe, Mn and Cu. In the fibrous root all macro- and micronutrients tended to concentrate with more intensity than in the main root.

In our work, we observed that the micronutrient concentration augmented sharply in root system especially with Gomera-1.

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