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Salt tolerance of mango rootstocks *(Magnifera indica* L. cv. Osteen)

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Abstract

The aim of this work was to establish the criteria to determine the relative tolerance of mango rootstocks *(Mangifera indica* L.) to high Cl^- and Na^+ concentrations present in irrigation water. Two rootstocks, Gomera-1 and Gomera-3 grafted with the cultivar Osteen, were subjected to study. Grafted plants were exposed to salinized irrigation waters measured by electrical conductivity (1.02, 1.50, 2.00 and 2.50 dS m^{-1}). Results indicated differences in retaining toxic elements in different organs (roots, stem, or leaves) of both rootstocks. Gomera-3 was more sensitive as took up higher amounts of Cl^- and Na^+ than Gomera-1. Gomera-1 was more tolerant, being the tolerance possibly associated with the capacity of this rootstock to restrict the uptake and transport of Cl^- and Na^+ ions from the root system to the aboveground parts. The Cl^- ions were more toxic in rootstock and cultivar leaves, while the Na^+ ions were more toxic in the roots. Therefore, the present study reveals that Gomera-1 proved to be the most adaptable rootstock to saline conditions, making it feasible for use in areas with low water quality.

Key words: Cl^- and Na^+ uptake, brackish water, subtropical orchards, salt stress.

Resumen

Tolerancia a la salinidad de portainjertos de mango *(Mangifera indica* L. cv. Osteen)

Con objeto de determinar los criterios más idóneos para estudiar la tolerancia relativa de portainjertos de mango *(Mangifera indica* L.) a altas concentraciones de Cl^- y Na^+ presentes en las aguas de riego, se sometieron a estudio dos portainjertos, Gomera-1 y Gomera-3, injertados con el cv. Osteen. Las plantas fueron expuestas a riego con aguas salinas medidas por medio de su conductividad eléctrica (1,02; 1,50; 2,00 y 2,50 dS m^{-1}). Los resultados indicaron diferencias en la retención de elementos tóxicos entre los tejidos de los diferentes órganos (raíces, tallo y hojas) de los portainjertos. El portainjerto Gomera-3 absorbió mayor cantidad de Cl^- y Na^+ que el Gomera-1, siendo por tanto más sensible. En cambio, Gomera-1 fue más tolerante, lo cual estaría asociado con su capacidad de restringir la absorción y transporte de Cl^- y Na^+ desde el sistema radicular hacia la parte aérea. El Cl^- fue mucho más tóxico en las hojas tanto del portainjerto como del cultivar, mientras que el Na^+ lo fue en las raíces. El presente estudio revela una mayor adaptabilidad de Gomera-1 a condiciones salinas, y hace factible su empleo como portainjerto en zonas con aguas de baja calidad.

Palabras clave: absorción de Cl^- y Na^+, aguas salobres, cultivos subtropicales, estrés salino.

Introduction

On the littoral band of the Spanish provinces of Granada and Malaga there is a large area dedicated to subtropical fruit production that covers approximately 13,000 ha, of which 8,500 are dedicated to avocado (*Persea americana* Mill.), 3,500 to custard apple (*Annona cherimolia* Mill.) and 1,000 to other species production (Calatrava, 1998). Around 800 ha of the latter are mango (*Mangifera indica* L.) that is expected to produce over 5,000 t $year^{-1}$ in the next few years due to the great productive potential of the area.

The use of poor quality waters on these subtropical crops has caused many problems due to the sensitivity of these fruit species to soluble salts, especially chlorides. The use of brackish waters for irrigation can increase the salt concentration in the soil and, consequently, hinder plant growth and reduce production (Alkilan *et al.*, 1997).

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Avocado and custard apple production was severely and irreversibly damaged by using these waters, salinated by marine intrusion to the main irrigation wells. Owing to these salinity problems, new species such as mango, tolerant to high salt concentrations were introduced. According to Kadman *et al.* (1976) and Gazit and Kadman (1980, 1983), mango rootstock 13/1, very popular in Israel, is tolerant to low quality waters. However, in the Southeast of the Spanish peninsula and in the Canary Islands this is used very little and the most commonly used rootstocks are Gomera-1 and Gomera-3 (Galan and Garcia, 1979; Galan and Fernandez, 1988 a, b). The ungrafted rootstock plants of Gomera-1 presented relative salt tolerance (Galan *et al.*, 1989).

On the other hand, the most widespread crops throughout the Southeast peninsula and the Canary Islands come from Florida (USA). The most important of these, owing to their commercial popularity and excellent flavours, include the cultivars Osteen, Keitt, Sensation, Lippens, Irwin, etc. (Galan, 1999).

In this work, salt tolerance induced by irrigation water was studied in mango plants cv Osteen grafted into the two main rootstocks existing in the area, Gomera-1 and Gomera-3.

Material and methods

The study was carried out during the period 29/06/1998-02/05/1999, on the Experimental Farm «El Zahori» belonging to the coastal municipality of Almuñecar (Granada). For the experiment, a homogeneous batch of 4 year-old young mango plants of the Osteen cultivar, grafted onto Gomera-1 (G-1) and Gomera-3 (G-3) rootstocks were used. 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 mg kg^{-1} 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 water used as control had a pH of 7.74, EC 1.02 dS m^{-1}, and 272.0, 171.0, 104.0, 3.10, 49.0, 4.70, 92.1 and 59.2 ppm of HCO_3^-, SO_4^{-2}, Cl^-, NO_3^-, Na^+, K^+, Ca^{2+} and Mg^{2+}, respectively. The adjusted sodium absorption ratio (adj. SAR) calculated was 2.33. Salt stress was induced by irrigation waters with increasing concentrations of Cl^- and Na^+. These solutions were prepared from the farm irrigation water. The control solution was A and NaCl was added to the three remaining treatment solutions (B, C and D) (Table 1). Two Netafim self-regulating drip emitters per plant providing 4 l h^{-1} applied the irrigation treatments.

Table 1. Characteristics of irrigation water used in the experiment

Type of water	NaCl added (g l^{-1})	EC 25 °C (dS m^{-1})	Chloride (mg l^{-1})	Sodium (mg l^{-1})	Adjusted S.A.R.
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

The plants were distributed into 4 blocks considering the pot as an experimental unit and assigning 6 units of each rootstock per block. All the rootstocks and treatments were randomised within each block. The experimental design was as follows: 4 (brackish waters) × 2 (rootstocks) × 6 (repeats), corresponding to a total of 48 plants.

The stem diameter of the cultivar was measured 10 cm from the junction (scar) between the rootstock and the cultivar. Over the experiment, monthly foliar samples of the cultivar were taken to determine the change in Cl^- and Na^+ concentrations in the leaves of the graft.

For the chemical analysis, all the samples were carefully washed with distilled water, dried at 70ºC for 48 hours until constant weight and then ground. The Na^+ and K^+ contents were determined by flame spectrophotometry (MAPA, 1971), the Ca^{+2} contents by atomic absorption (Chapman and Pratt, 1961), and the Cl^- by the silver nitrate approach (Gilliam, 1971).

For a comparative-qualitative study of the foliar symptoms, the severity of the plant's condition was classified as follows: plants without symptoms (WS), very mild chlorosis (VMC), partial mild chlorosis (PMC), mild chlorosis to burns on the margins and apices of the lower leaves (BMA), intense damage due to burning of all the foliage (BAF) and severe damage with leaf loss followed by plant death (SDD).

The fresh weight of the plants was measured and then the corresponding samples were taken from the plant's organs as follows: Osteen cultivar leaves (CL), cultivar stem, including branches (CS), rootstock leaves (RL), rootstock stem (RS), main root (MR) and fibrous root of rootstock (FR) (Fig. 1). The dry matter

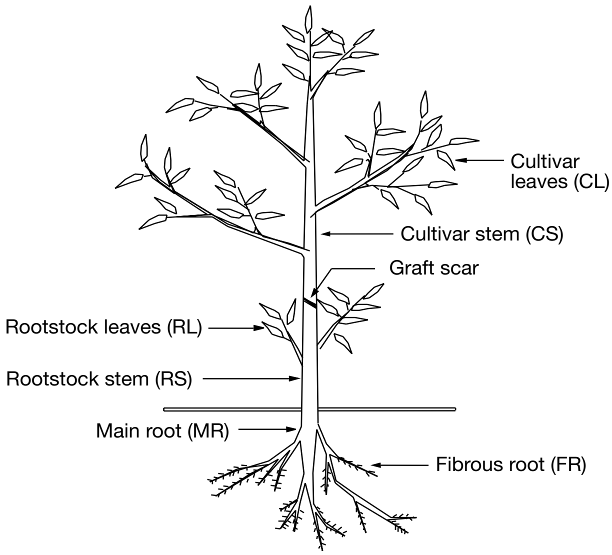

Figure 1. Samples taken from the mango plant.

produced in each of the treatments was determined in these samples.

Analysis of variance (ANOVA) was applied to assess the effect of the EC of the waters and the rootstock on the height, diameter, weight and concentration of Cl^- and Na^+ in leaves, stem and root. The means were separated by Duncan's multiple range test at around 0.05. The Statgraphics 4.1 analytical software was used.

Results and Discussion

Visual assessment of the symptoms plant height, diameter and weight

The experiment was completed around 10 months (04/1999) after starting all the treatments. It was decided to suspend the irrigation and to evaluate the effects, from total leaf fall and plant death in the most saline treatment D (2.5 dS m^{-1}) to the start of a generalised behaviour in the other treatments. The soils in the most saline treatment showed clear evidence of structure loss and dispersion of the clay, compared to the soils in the control pots.

From the visual assessment, it was clearly established that plants with the Gomera-3 rootstock were the most affected by the salt treatments. Table 2 shows the evolution of the foliar symptoms of toxicity in the cultivar for both rootstocks studied as the EC of the irrigation solutions increased. It can be seen that the symptomatology in the plants of both rootstocks was similar until treatment B (1.5 dS m^{-1}), presenting very mild symptoms (VMC). Visual differences were observed with treatments C (2.00 dS m^{-1}) and D (2.50 dS m^{-1}), and at these levels of conductivity plants with Gomera-3 exhibited more acute symptoms than those with the Gomera-1 rootstock. Hence, if we use foliar symptoms as criteria of tolerance (or sensitivity) to Cl^-, we can conclude that of the two rootstocks studied, Gomera-3 was the most sensitive and Gomera-1 the most tolerant. However, according to Kadman (1963) it is inadvisable to evaluate the sensitivity to salts exclusively on the basis of the severity of apparent symptoms. For this reason, we also use other criteria such as plant height, diameter and fresh weight.

In both rootstocks, there were statistically significant differences in the mean heights and diameters of plants in treatments A and B and of treatments C and D (Table 2). The difference was even greater in the plants' fresh weights, especially with Gomera-3 rootstock. Because of the saline conditions, the height, diameter and weight of the plants were reduced. The three measurements made in each of the plants were larger

Table 2. Symptoms, height, stem width and fresh weight of the plants in each treatment using rootstocks Gomera-1 or Gomera-3

Treatment	Symptoms[1]	Height	Diameter	Fresh weight	Symptoms	Height	Diameter	Fresh weight
	Gomera-1				Gomera-3			
A	WS	114.8a	19.4a	970.7a	WS	116.7a	19.8ab	976.0a
B	VMC	111.1a	18.1a	856.7b	VMC	116.6a	20.6a	890.3b
C	PMC	99.0b	14.7b	849.6b	BMA-BAF	110.3b	19.6ab	875.0c
D	BAF	94.4c	15.8b	783.3c	BAF-SDD	101.6c	16.2b	788.6d
ANOVA EC	*	*	*	*	*	*	*	*

[1] According to the comparative-qualitative analysis of foliar symptoms. The mean values in the columns followed by the same letter are not significantly different when compared by Duncan's multiple range test at 5%. * Significant at 0.05.

in Gomera-3 rootstock. The reduced height, diameter and fresh weight of the Gomera-1 plants of the most saline treatment (D) compared to the control (A) was 18%, 19% and 19% respectively. In the case of plants with Gomera-3, the reduction was 13%, 18% and 19%, respectively. These results suggest that Gomera-1 plants were the most affected by salinity (Table 2). The results of this work coincide with others that demonstrate a negative influence of salinity on the growth of mango (*Mangifera indica* L.) (Schmutz and Ludders, 1993), avocado (*Persea americana* Mill) (Wiesman, 1995; Bernstein *et al*., 2001) and citrus rootstocks (*Poncirus trifoliata* L.*, Citrus aurantium* L., *Citrus sinsensis* L., *Citrus aurantifolia* L.) (Tozlu *et al.*, 2000; Garcia *et al*., 2002) and pear trees (*Pyrus betulifolia* Bunge and *Pyrus pyrifolia* Burm f. Nakai) (Okubo *et al*., 2000). Galan *et al.* (1989) determined, in greenhouse conditions and with one-year old ungrafted mango plants, that the visual symptoms due to salinity were less intense in Gomera-1 than in the other rootstocks. They also observed little difference in the diameter and height of the plants in conditions of salt stress. In our experience, the influence of the Osteen cultivar on graft behaviour and vice versa was especially important, which ultimately represents the presence of the plant in the field for production purposes.

Dry matter produced in the different plant organs

Significant differences were observed in the production of dry matter of all the organs, both of the rootstock and the cultivar, with the exception of RL of Gomera-1 and CL, CS and RL of Gomera-3 between the control and treatment B.

The negative association established between the production of dry matter of the tissues in each of the organs and the salinity of the irrigation waters was more intense in the root system. The effect was greatest in the Gomera-3 plants, especially in the fibrous roots. The tissues with the least relative sensitivity were the leaves of both rootstocks. The cultivar leaves with Gomera-3 were affected more than those of Gomera-1. The reduction in dry matter in the rootstock and cultivar stems in the Gomera-1 plants was similar. However, in Gomera-3 plants the reduced dry matter of the rootstock stems was greater than in those of the cultivar (Table 3).

The linear reduction in dry matter with increased salinity coincides with previous studies on avocado (*Persea americana* Mill) (Chirachint and Turner, 1988), sugar cane (*Sacharum* spp. hybrid) (Plaut *et al.,* 2000) and citrus rootstocks (*Poncirus trifoliata* L.) (Tozlu *et al*., 2000). In our case, the production of dry matter in plants with Gomera-3 was the most affected in spite of their greater height, diameter and weight. These results coincide with those obtained from a work that demonstrated the greater robustness of Gomera-3 compared to Gomera-1, mainly due to the capacity of the root system for nutrient uptake (Duran, unpublished data). In both rootstocks, as mentioned previously, the production of dry matter in the fibrous and main roots was more sensitive than in other organs. However, it was less intense in the fibrous roots of Gomera-1, suggesting in this rootstock the existence of a very important response mechanism to salt stress.

Clearly, the results obtained from the three criteria (visual symptoms, height, diameter and fresh and dry weight) indicated a greater tolerance of Gomera-1 rootstock to salinity.

Concentration of chloride and sodium in the organs studied

The high concentration of NaCl in the irrigation waters produced a rise in the Cl^- contents in all the plant organs and of Na^+ in most of them (Fig. 2). The concentration of Cl^- was higher than that of Na^+, and there was a clear tendency to concentrate both ions in the rootstock leaves, with more intensity in Gomera-3 (Fig. 2a and 2b). Similarly, Nieves *et al.* (1991) and Storey (1995) also described that, in saline conditions, the concentration of Cl^- ions was higher than that of Na^+ ions in the foliar mass of citruses. The Cl^-concentration in cultivar leaves of most saline treatment respect to the control was 6.4 and 5-fold greater with Gomera-1 and Gomera-3, respectively. In the rootstock leaves the increase was 5-fold in Gomera-1 and 7-fold in Gomera-3.

The stem tissues of the Gomera-3 rootstock were distinguished in that they also retained more Cl^- ions than those of Gomera-1. This prevents a more active transport to tissues of the cultivar stem (Fig. 2c and 2d).

In contrast to Cl^-, which mainly concentrates in the rootstock stem, Na^+ accumulated in the cultivar stem, being an inverse relationship between the two. The results were similar to those obtained by Chirachint and Turner (1988) and Weisman (1995) with avocados,

Table 3. Effect of salinity on the production of dry matter (%). Reduction in relative weight of salt-treated plants compared to the control (%)

Treatment	CL	CS	RL	RS	MR	FR
Gomera -1						
A	52.5a	39.5a	51.0a	41.5a	45.5a	31.5a
% red. weight	100	100	100	100	100	100
B	49.5b	36.0b	49.5a	38.5ab	43.5a	27.0ab
% red. weight	94	91	97	93	96	86
C	48.0bc	34.0bc	48.5ab	36.0bc	36.5b	23.5b
% red. weight	91	86	95	86	80	75
D	45.5c	32.5c	45.5b	34.0c	33.0b	23.5b
% red. weight	87	82	89	82	72	75
ANOVA EC	*	*	NS	*	*	*
Gomera -3						
A	51.0a	39.0a	49.5a	45.5a	45.5a	32.5a
% red. weight	100	100	100	100	100	100
B	50.5a	37.0a	48.5a	42.0ab	42.0ab	28.0b
% red. weight	99	95	98	92	92	86
C	48.0a	34.5ab	44.5b	38.0bc	38.0bc	25.0c
% red. weight	94	88	90	84	84	77
D	41.5b	31.5b	44.0b	35.5c	33.5c	21.5d
% red. weight	81	81	89	78	74	66
ANOVA EC	*	*	*	*	*	*

CL: cultivar leaves. CS: cultivar stem. RL: rootstock leaves. RS: rootstock stem. MR: main root. FR: fibrous root. Means in the columns followed by a same letter are not significantly different according to a Duncan's multiple range test at 5%. NS: not significant. * Significant at 0.05.

who established that Na^+ tends to accumulate in the stem tissues and in branches of the graft, and in the roots of the rootstock.

The concentration of toxic ions in the roots, on being in direct contact with the soil, clearly increased compared to the control in all the treatments (Fig. 2e and 2f). As with the leaves and stems, the concentration of Cl^- in the roots was greater in the Gomera-3 plants than in the Gomera-1. A similar effect to that of Cl^- was observed with the Na^+ concentration in the fibrous and main root, and in all the other treatments in which its concentration increased by more than 100% compared to the control.

Our results reveal a linear relationship between the concentration of Cl^- and Na^+ ions in the roots and increased salinity of the irrigation waters. Schmutz and Ludders (1993) described a similar tendency in the '13/1' mango rootstock. In both rootstocks the maximum concentration of Cl^- ions was found in the leaves, followed by the roots and stem. In the case of Na^+, the maximum value was recorded in the root followed by the stem and the leaves.

Table 4 shows the results of the variance analysis, in which a generalised increase in Cl^- and Na^+ was observed in all the plant organs, both in Gomera-1 and in Gomera-3, with statistically significant differences compared to the control. The concentration of ions in the leaf, stem and root was lower in the Gomera-1 plants. Similar results were found by Galan *et al.* (1989) with ungrafted plants, indicating that the concentration of Cl^- and Na^+ ions in leaves and root of Gomera-1 is lower than that found in other rootstocks. The toxic action of a high concentration of Cl^- strongly affected the plant leaves causing defoliation, a very specific defence strategy of theirs to eliminate Cl^- and Na^+. The characteristic way rootstocks behave in the presence of high concentrations of Cl^- is evident, i.e. by retaining a large proportion of this ion in all of its

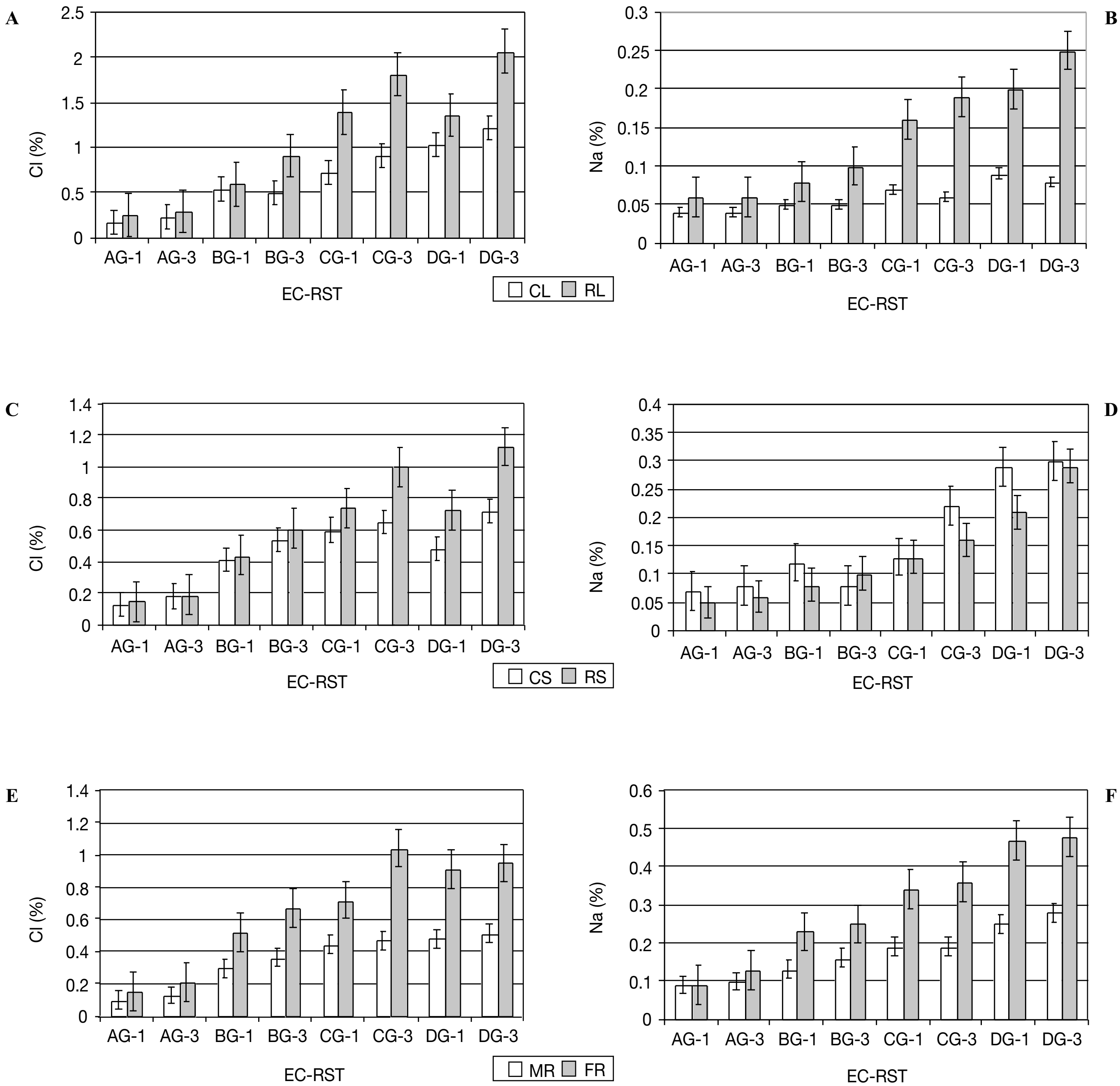

Figure 2. Concentration of Cl^- and Na^+ ions in leaves of the cultivar Osteen and the rootstock (A and B), in the cultivar stem and the rootstock (C and D), and in the main root and fibrous root (E and F) in each of the treatments and rootstocks Gomera-1 (G-1) and Gomera-3 (G-3). EC-RST = Combination EC of the water and the rootstock. The vertical bars represent the standard error of the mean, n = 6.

organs. Sykes (1985) and Syvertsen *et al.* (1988) described that Na^+, and especially Cl^-, tend to accumulate most in the lower or mature leaves, that in our case corresponded to the rootstock leaves, and to a lesser extent in the apical part, which, in our experiment, corresponded to the younger cultivar leaves.

Similarly, Emblenton and Jones (1966) reported that salinity problems in mango arise with electrical conductivity of the soil saturation extract higher than 1.4 dS m^{-1}, and Gazit (1970) in irrigation water with more than 200 mg l^{-1}, these limits were probably exceeded in our experiments with water types C and D.

Table 4. Mean contents of Cl^- and Na^+ in the tissues of the different organs of mango plants with each rootstock

	Gomera-1		Gomera-3	
	Cl^- (%)	Na^+ (%)	Cl^- (%)	Na^+ (%)
LEAF				
Treatment				
A	0.16a	0.05a	0.23a	0.05a
B	0.56b	0.06a	0.70b	0.07a
C	1.05c	0.11b	1.35c	0.12b
D	1.19d	0.14c	1.64d	0.16b
Tissue				
CL	0.61a	0.06a	0.71a	0.05a
RL	0.88b	0.12b	1.25b	0.15b
ANOVA				
EC	*	*	*	*
TIS	*	*	*	*
EC-TIS	*	*	*	*
STEM				
Treatment				
A	0.14a	0.06a	0.18a	0.07a
B	0.46b	0.10ab	0.56b	0.09a
C	0.67c	0.13b	0.84c	0.18b
D	0.61c	0.25c	0.92c	0.29c
Tissue				
CS	0.41a	0.15a	0.52a	0.17a
RS	0.51a	0.12b	0.73b	0.15a
ANOVA				
EC	*	*	*	*
TIS	NS	*	*	NS
EC-TIS	NS	NS	NS	NS
ROOT				
Treatment				
A	0.12a	0.09a	0.17a	0.11a
B	0.41b	0.18b	0.51b	0.20b
C	0.58c	0.27c	0.75c	0.27c
D	0.80d	0.36d	0.71c	0.35d
Tissue				
MR	0.35a	0.16a	0.36a	0.17a
FR	0.61b	0.28b	0.72b	0.30b
ANOVA				
EC	*	*	*	*
TIS	*	*	*	*
EC-TIS	*	*	*	*

CL: cultivar leaves. CS: cultivar stem. RL: rootstock leaves. RS: rootstock stem. MR: main root. FR: fibrous root. TIS: organ tissues. The means in the columns followed by a same letter are not significantly different according to a Duncan's multiple range test at 5%. NS: not significant. * Significant at 0.05.

There were significant differences between the concentrations of Na^+ in the cultivar and the rootstock stems, and this difference was greater in the former in Gomera-1 plants (CS>RS). A similar tendency was observed in the Gomera-3 plants, although this was not statistically significant. These results seem to indicate that active transport of Na^+ from the cultivar stems to the leaves was, in some way, repressed. Levy and Shalhevet (1990) and Lloyd *et al*. (1990) described an influence of the graft on retention and accumulation of Na^+ with citrus plants in saline conditions. Similarly, Behboudian *et al.* (1986) found that Na^+ accumulation mainly depends on the rootstock, although it also plays an important role in the cultivar. In conditions of saline stress, Na^+ tends to concentrate in the roots of the rootstock. Tozlu *et al.* (2000) observed that, in saline conditions the most toxic effect of Na^+ on *Poncirus trifolita* L. was produced in the root system. Similarly, the concentration of Na^+ was higher in fibrous roots than in the main root (FR>MR), especially in G-3.

The results obtained suggest that the exclusion mechanisms of Cl^- in Gomera-1 will be located in the root system, restricting the entry of Cl^- ions. There is also the possibility that Gomera-1 has a continuous replacement mechanism from the fibrous roots. The loss of fine roots, due to the presence of Cl^-, is closely linked to a continuous production of new roots. In this way, the plant could endure the saline stress by indirectly eliminating the toxic ion through the dead tissue. The results of the present work with young plants coincides with those of a previous study in field conditions in which it was found that mango trees in full production grafted into Gomera-1 rootstocks were more tolerant and productive in conditions of high salinity (Martinez *et al.*, 1999).

Distribution of Cl^- and Na^+ in the organs compared to the whole plant

The patterns of distribution and accumulation of the toxic ions in the organs of each rootstock present some similarity with those obtained in the whole plant for all the treatments. However, the concentration of Cl^- in the fibrous roots of Gomera-1 was higher than in those of Gomera-3, indicating that this rootstock actively accumulated this ion impeding its transport in the stem and leaves (Fig. 3a and 3b). Build up of ions in both the cultivar main root and stem decreased in all the salt treatments compared to the control. The increased propor-

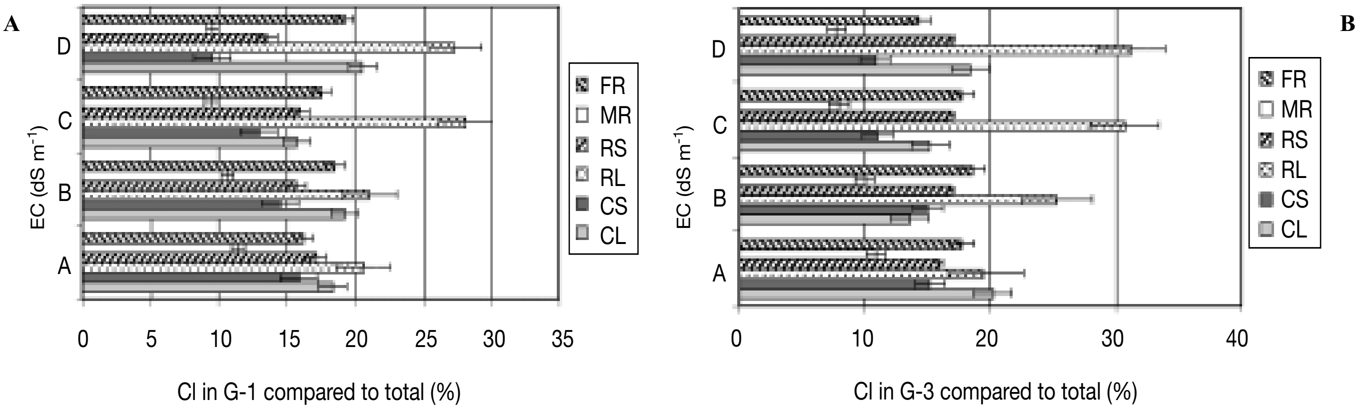

Figure 3. Distribution and accumulation of Cl^- in the organs of the cv. Osteen and rootstocks Gomera-1 (A) and Gomera-3 (B), relative to the total amount absorbed by the plant in each of the treatments. CL: cultivar leaves. CS: cultivar stem. RL: rootstock leaves. RS: tootstock stem. MR: main root. FR: fibrous root. The vertical bars represent the standard error of the mean, n = 6.

tion of Cl^- in the rootstock leaves relative to the total was also similar in both cases. In the cultivar leaves the proportion remained the same in all the treatments relative to the total amount. The distribution and accumulation of Cl^- in the organs of Gomera-1 was RL>CL>FR>>RS>CS>MR, whereas in the case of Gomera-3 this was RL>FR>RS>CL>CS>MR.

The distribution and accumulation of Na^+ in most of the organs of the plant with rootstock Gomera-1 tended to be greater than in the plants with Gomera-3 (Fig. 4 a and 4b). In both rootstocks, Na^+ accumulation increased in the cultivar stem impeding its transport to the leaves. A similar tendency was observed in the rootstock stem in which accumulation of Na^+ relative to the total amount absorbed by the plant increased in all the saline treatments. The fibrous roots of the plants with Gomera-1 accumulated more Na^+ than with Gomera-3. The main root of both rootstocks tended to concentrate less Na^+ in saline conditions, as occurred with Cl^- in this organ. Hence, the root system of the Gomera-1 rootstock, especially the fibrous roots, was capable of concentrating a greater proportion of the total amount of Na^+ ions absorbed by the plant. The accumulation of Na^+ in the organs of both rootstocks was: FR>MR>CS>RL>RS>CL.

In general, the dynamics of Cl^- between the tissues in each of the organs was practically the same for all saline treatments. This seemed to indicate the absence of any mechanism to prevent movement or active accumulation of this ion inside the plant apart from that due to the nature of the rootstock itself that accumulated a large amount of toxic ions in its tissues. In the case of Na^+, however, probably the gradual increase in the cultivar leaves can be attributed to a mechanism that restricts the movement of this ion inside the plant, initially in the tissues of the fibrous roots of the root-

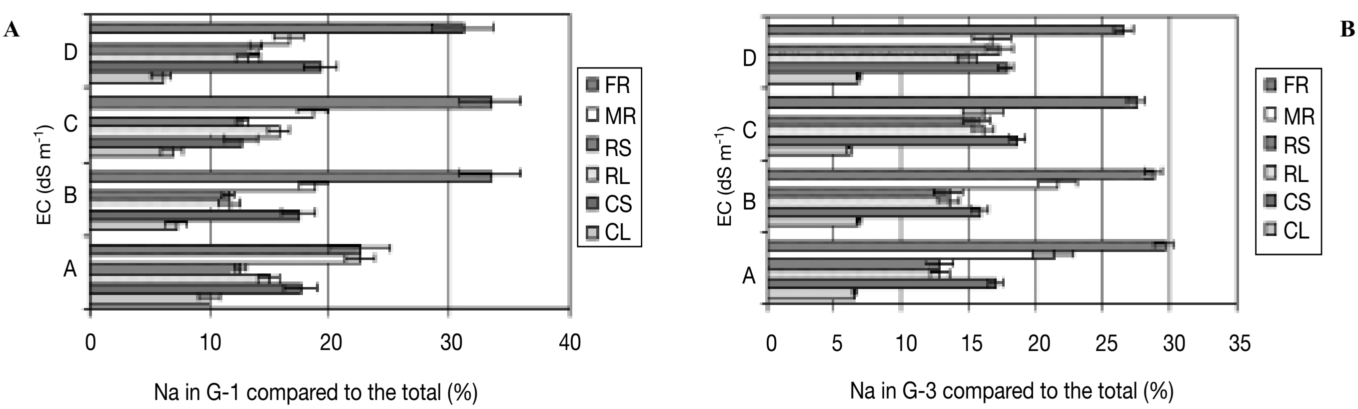

Figure 4. Distribution and accumulation of Na^+ (%) in the organs of cv. Osteen and rootstocks Gomera-1 (A) and Gomera-3 (B), relative to the total amount absorbed by the plant in each treatment. CL: cultivar leaves. CS: cultivar stem. RL: rootstock leaves. RS: tootstock stem. MR: main root. FR: fibrous root. The vertical bars represent the standard error of the mean, n = 6.

stock and then in the cultivar stem. Lloyd *et al.* (1989), working with citruses in saline conditions, emphasised the influence of the grafted cultivar on the retention of toxic ions when the rootstock had little ability to do this.

The results suggest that the exclusion mechanism of Na^+ can be operatively active at low concentrations of NaCl, but ineffective at high salinity. Similarly, an important proportion of Na^+ was probably transported from the leaves through the phloem to the root in contrast to the Cl^-, which accumulates in the leaves producing burns, nutritional imbalances (Durán, unpublished) and reduced transpiration (Schmutz and Ludders, 1993).

All these results suggest that, while Cl^- ions are most toxic in the cultivar and rootstock leaves, the Na^+ ions are most toxic in the rootstock roots.

Therefore, the present comparative study reveals that Gomera-1 proved to be the most adaptable to high Cl^- and Na^+ concentrations, making it feasible for use in areas with low water quality.

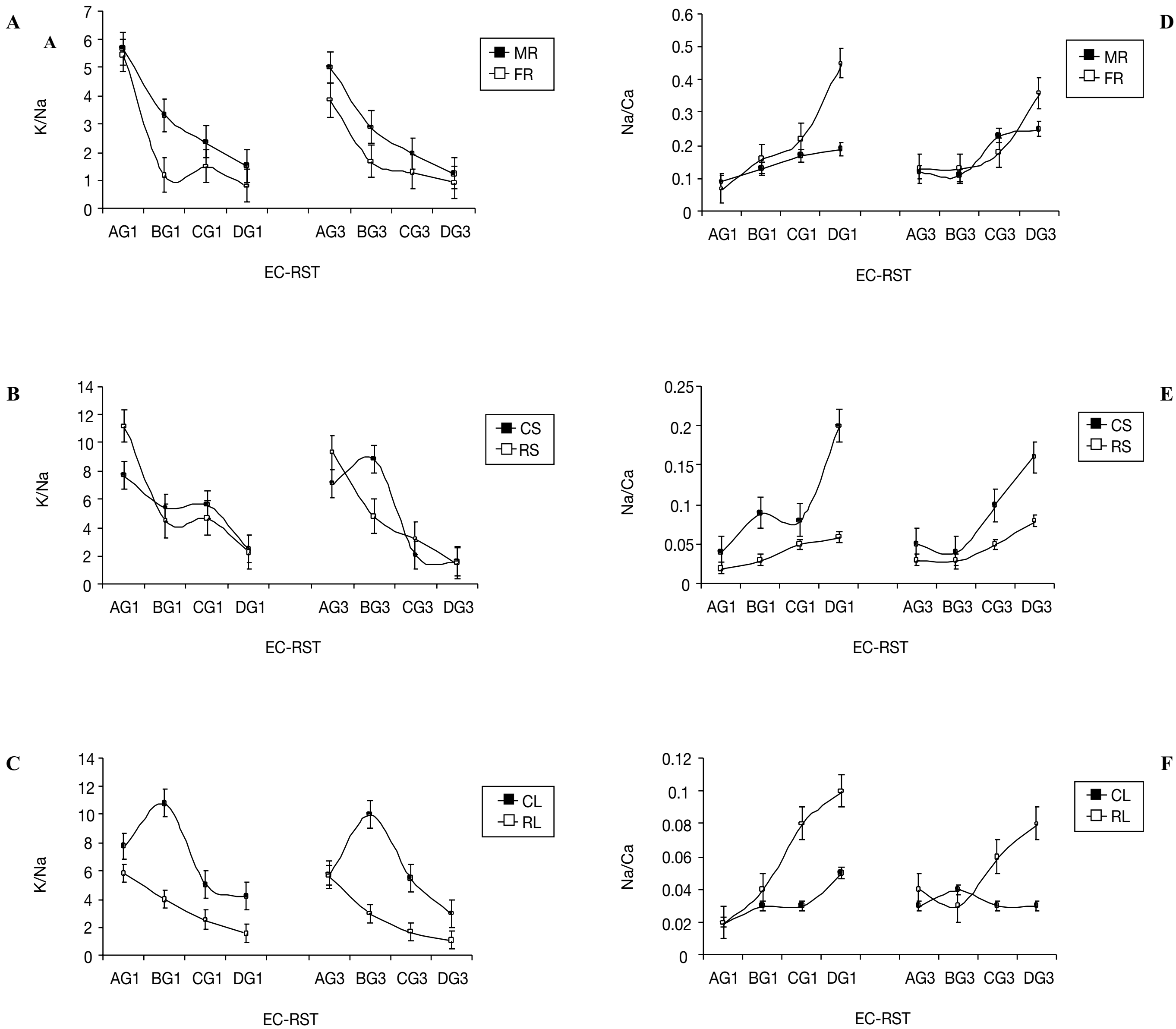

Figure 5. K^+/Na^+ ratios in root (A), stem (B) and leaf (C) and of Na^+/Ca^{2+} in root (D), stem (E) and leaf (F), in each of the treatments and rootstocks Gomera-1 (G-1) and Gomera-3 (G-3). EC-RST: combination EC of water and rootstock. CL: cultivar leaves. CS: cultivar steam. RL: rootstock leaves. RS: rootstock stem. MR: main root. FR: fibrous root. The vertical bars represent the typical error of the mean, n = 6.

K^+/Na^+ and Na^+/Ca^{2+} ratios in all the organs

To best understand the effects of NaCl in irrigation waters on mango plants changes in K^+ levels were studied, as one of the most important solutes. K^+ plays a crucial role in maintaining the osmotic potential especially in the roots, which is essential for transport through the xylem and for the plants' water balance.

The K^+/Na^+ ratio was affected by the NaCl concentration and decreased in the roots, especially in the fibrous roots (Fig. 5a). It, therefore, seems that there is an important exchange of Na^+ and K^+ in the root tissues (Cerda *et al.*, 1995; Garcia *et al.*, 2002). Similarly, the effects of salt stress on the K^+/Na^+ ratio suggest that some of the K^+ from the fibrous roots or the main root was transported to the leaves, to a greater extent in the plants with Gomera-1. This could be beneficial in the presence of excess Cl^- in the leaf tissues. Similarly, in some plant species the negative effect of this ion on the cells of the foliar mass is reduced by the presence of K^+ (Schnabl, 1980).

The K^+/Na^+ ratio in the stem also tended to diminish with salinity (Fig. 5b). A similar phenomenon to that observed in the roots occurred especially in the rootstock leaves. Moreover, the K^+/Na^+ ratio increased with treatment B (1.5 dS m^{-1}) in the two rootstocks (Fig. 5c). In the case of the cultivar leaves, this ratio was greater in the plants grafted with Gomera-1. In normal conditions, a rise in the K^+/Na^+ ratio in the plant, especially in the leaves, is important and beneficial. Probably because of this, the leaves of the cultivar with Gomera-1 had less negative effects due to the Cl^- ions, directly reflected in the visual symptoms described previously.

The importance of the calcium deficit in the plants, due to one cause or another, can produce anomalies in their development. This is the case of 'bitter pit' in apples (*Malus domestica* L.) and pears (*Pyrus communis* L.) or 'soft nose' in mango (Wainwright and Burbage, 1989).

Table 5. Concentration of Cl^- and Na^+ in leaves of the cv. Osteen grafted in rootstocks Gomera-1 or Gomera-3

Treatment	Cl^- (%)	Na^+ (%)	Cl^- (%)	Na^+ (%)
	Gomera-1		Gomera-3	
A	0.135a	0.046a	0.177a	0.048a
B	0.280ab	0.054b	0.311ab	0.053a
C	0.414bc	0.060bc	0.459bc	0.062b
D	0.529c	0.065c	0.579c	0.074c
ANOVA				
EC	*	*	*	*
MON	*	*	*	*
EC-MON	*	*	*	*

The means in the column followed by a same letter are not significantly different according to Duncan's multiple range test at 5%. MON: sampling month. * Significance at 0.05.

The Na^+/Ca^{2+} ratio tends to rise with the NaCl concentration and this increase is greater in the fibrous root of rootstock G-3 (Fig. 5d). Similarly, Kent and Lauchli (1985) and Hansen and Munns (1988) described that root growth and function can be restricted by a high Na^+/Ca^{2+} ratio. A similar phenomenon occurred in the cultivar stem in which the Na^+/Ca^{2+} ratio was higher than in the rootstock stem (Fig. 5e). Finally, the Na^+/Ca^{2+} ratio in the rootstock leaf was higher than that in the cultivar (Fig. 5f), and the values were much higher in plants with the Gomera-1 rootstock. Many studies described a reduced K^+ concentration in the tissues resulting from an increased Na^+/Ca^{2+} ratio (Nakamura *et al.*, 1991; Subbarao *et al.*, 1990).

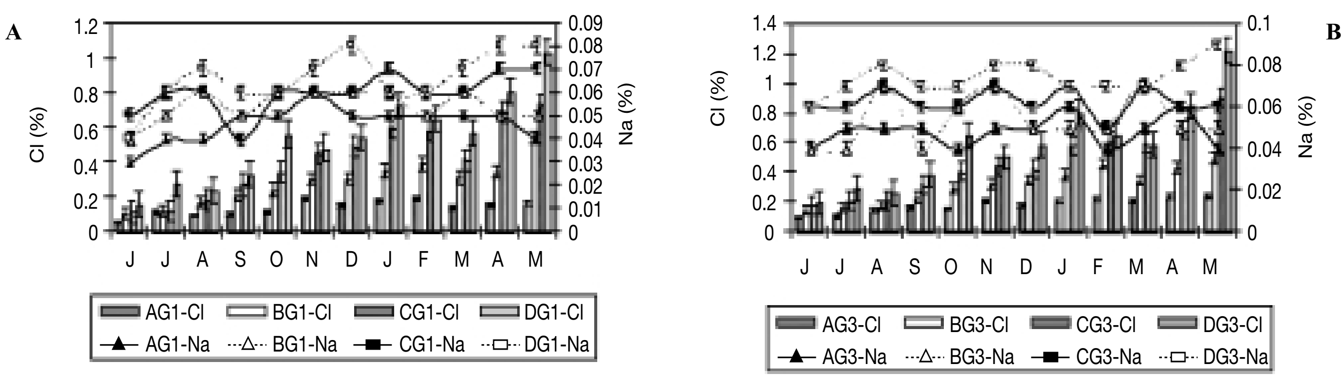

Figure 6. Mean foliar concentration of Cl^- and Na^+ in leaves of the cv. Osteen with Gomera-a (A) and Gomera-3 (B) plants in each of the treatments. Vertical bars represent the typical error of the mean, n = 6.

Foliar concentration of chloride and sodium ions

Over the duration of the experiment, monthly foliar samples of the cultivar were taken to establish the evolution of the Cl^- and Na^+ ions. Table 5 shows the results obtained over the experimental period. Plants with the Gomera-1 rootstock tended to maintain a lower foliar concentration, and there were statistically significant differences in the influence of the two rootstocks on the mean Cl^- and Na^+ concentrations.

The concentration of Cl^- in the leaves of the cultivar with the two rootstocks increased steadily with the saline level, confirming the tendency towards a greater absorption of Cl^- by Gomera-3 (Fig. 6a and 6b).

The rise in Na^+ concentration during the months of the study was not as rapid or linear as in the case of Cl^-, but was more gradual. There was a slight tendency for the plants grafted in Gomera-3 to absorb more of this element. As mentioned previously, a considerable proportion of Na^+ in saline conditions would accumulate in the roots of the rootstock and in the cultivar stem hence the concentration of this ion would be lower in the leaves (Fig. 6a and 6b).

Duran *et al.* (2002), in mango trees cv. Keitt, found a similar phenomenon concerning the greater potential of the Gomera-3 compared to the Gomera-1 rootstock to absorb nutrients and then to transport them to the foliar mass of the grafted cultivar.

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