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Salt Effects on Growth and Ion Uptake of Pistachio Rootstock Seedlings

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Abstract. **The degree of salt resistance of *Pistacia* spp. grown in the western United States is not adequately known. This study evaluated seedling growth and ion uptake characteristics of two *Pistacia* spp. and one hybrid in outdoor lysimeters for two seasons. After 12 weeks, seedling stem elongation of *P. atlantica* Desf., *P. terebinthus* L. (three selections), and *P. integerrima* Stewart × *atlantica* (referred to as Gold II) was reduced by an average of 33% at soil solution salinity of 12.6 dS·m^{-1} (or 8.0 dS·m^{-1} in the saturation extract). Gold II was the most vigorous genotype and produced the greatest biomass in control and high-salt solutions. Decreases in root and stem growth (average of all seedlings combined) occurred at soil solution salinity of 13.8 dS·m^{-1} (or 8.7 dS·m^{-1} in the saturation extract). Increasing salinity resulted in a higher root to stem ratio, which was most pronounced in *P. terebinthus.* Comparatively small but significant differences in leaf Na and Cl concentrations between species and selections occurred. All species limited Na transport to leaf tissue up to 125 meq Na/liter in soil solution, storing the greatest amount in roots. Chloride concentrations on a dry-weight basis were substantially higher in leaves than in roots. Increasing salinity did not affect leaf K and Mg concentrations, whereas Ca was significantly reduced. Leaf Na and Cl concentrations of *P. atlantica* and *P. terebinthus* had significant correlation with Na and Cl concentrations in soil solutions (r = *0.83 to *0.94).**

Domestic cultivation of pistachio, *P. vera* L., began in California and has recently increased in Arizona, southern New Mexico, and far west Texas. These areas are frequently affected by high salinity, and pistachio, which has been described as salt-tolerant (Sepaskhah and Maftoun, 1981; Behboudian et al., 1986), is potentially an alternative to salt-sensitive pecan *[Carya illinoensis* (Wangenh.) C. Koch.] or almond *(Prunus amygdalus* Batsch). *P. atlantica, P. terebinthus,* and *P. integerrima* are the major rootstock of the domestic pistachio industry. However, the responses of these species to salinity in southwestern growing conditions have not been adequately studied. Most investigations have been made in a greenhouse environment and confined to *P. vera* scion cultivars not grown in the United States (Parsa and Karimian, 1975; Sepaskhah and Maftoun, 1981, 1982; Sepaskhah et al., 1985). These studies have demonstrated that growth rates of *P. vera* cultivars decrease with increasing NaCl concentration in culture solutions and that a positive correlation exists between Na as well as Cl concentrations in plant tissue and in the culture solutions. Although direct evidence is yet to be determined, some believe that Cl and possibly Na may cause specific ion effects in pistachio. Sepaskhah and Maftoun (1982), for instance, have suggested that differential salt sensitivity of *P. vera* cultivars may be related to the degree of Na and Cl accumulation in the plant. Scorching of bearing 'Kerman' leaves with high accumulation of Cl has been observed in California orchards (Ashworth et al., 1985).

If Na and Cl cause injury when accumulated to high concentrations in leaves, the selection of rootstock having low Na and Cl uptake characteristics may increase salt resistance of grafted trees. This possibility was demonstrated in stone fruits and grapes with respect to Cl (Bernstein et al., 1956, 1969). In these studies, rootstock had pronounced effects on Cl uptake, leaf damage, and growth. The study reported here was made to characterize growth responses and ion uptake of *Pistacia* spp. used as rootstock.

Materials and Methods

Seeds of *P. atlantica* (PI 246336) and *P. terebinthus* A, B, and C were sprouted in moist muslin cloth at 20C. Seed of *P. terebinthus* were first scarified in concentrated H_2SO_4 for 90 min (Crane and Forde, 1974). After radicle emergence, seeds were planted in moist 'Jiffy 7' pellets (Jiffy Products of America, Batavia, Ill.) and grown in a greenhouse for 2 months. *P. integerrima* × *atlantica* seedlings, also started in peat pellets, were purchased from a local nursery. This hybrid rootstock, referred to as Gold II in the pistachio industry, is not clonally propagated.

Seedlings between 10 and 15 cm tall were transplanted on 27 and 28 May 1986 into outdoor lysimeters (unit dimension of 1.2 × 1.1 × 0.6 m in depth) located at the Texas A&M Univ. Agricultural Research Center at El Paso. The lysimeters contained Bluepoint fine loamy sand (calcareous, mixed, thermic, Typic Torripsamment) to a depth of 0.50 m with a 5-cm underlay of coarse sand in which polyethylene tubes were embedded for drainage. Seedlings were planted in rows 13 cm apart with 25 cm between rows in a three-row planting with eight plants per row, or 24 plants per lysimeter.

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Abbreviations: EC_e, salinity of soil saturation extract; EC_s, salinity of soil solution; Na_s, soil solution Na concentration; *P. terebinthus* A, PI 246341; *P. terebinthus* B, PI 246342; *P. terebinthus* C, 041-9; Gold H, Pioneer Gold II.

Saline treatments (Table 1) began on 11 July 1986, when seedling height of all rootstocks averaged 14.5 cm, and continued for two seasons. Solution 1 (control) represents the quality of water from the Rio Grande River, and solutions 2, 3, and 4 represent increasing salinity. Solution 5 allows for evaluation of reduced Na concentrations (or increased Ca and Mg proportions) and solution 6 for evaluation of increased Cl relative to solution 3. All solutions were applied to *P. atlantica* and *P. terebinthus* A and B, while *P. terebinthus* C and Gold II were treated with solutions 1, 3, and 4 only, due to limited supply of these seedlings. Plants were subjected to solution 4 in a stepwise manner, first to two-thirds strength (the equivalent of solution 3), then to the full strength in the next irrigation.

All solutions were applied by flood irrigation in an amount to cause a 30% leaching fraction when the soil moisture in the lysimeters (measured periodically with a neutron probe) was depleted to about one-half of the total storage measured 1 day after irrigation. The moisture content 1 day after irrigation averaged 0.30 $m^3 \cdot m^{-3}$.

Daily records of rainfall and U.S. Weather Bureau Class A pan evaporation were recorded ≈ 100 m from the lysimeters. Monthly precipitation, averaged for both growing seasons, was 0.8, 53, 54, 42, and 12 mm, for May, June, July, August, and September, respectively. Average precipitation during the other months (Oct. 1986 to Apr. 1987) was 3 mm, with the highest amount recorded in Dec. 1986 (8 mm). Monthly evaporation averaged 262 mm during the growing season and 120 mm for the dormant period. Cumulative evaporation was typically 2- to 3-fold higher than cumulative rainfall (monthly basis), both during the dormant period and between irrigations. There was no indication of leaching from the drainage tubes following rainfall events. Occasionally, rainfall increased neutron probe readings, resulting in a 1- to 2-day delay in solution irrigation.

A modified 0.5-strength Hoagland nutrient solution no. 1, without Ca, Mg, and S (Hoagland and Arnon, 1950), was applied during, the growing seasons at monthly intervals (July to Aug. 1986 and Mar. to Aug. 1987). An earlier study indicated this strength to be sufficient for *P. vera* seedlings grown in sand culture (Parsa and Wallace, 1980). For each application, rates of N, P, and K were 55, 8, and 40 $kg \cdot ha^{-1}$, respectively. Trace elements were also added at the 0.5-strength concentration.

The EC_e (U.S. Salinity Laboratory Staff, 1954) was measured using three samples per treatment collected from 0 to 0.5-m depth at the end of the 1986 season (29 Sept.) and the start and end of 1987 (29 June and 7 Aug.). The concentrations of Cl, Ca, Na, and Mg in the soil saturation extract were determined at the start and end of the second season using the instrumental methods described later.

At the end of the first season (3 Oct. 1986), seedling terminal stem length increase from the start of treatments was measured. Branching of seedlings in the second growing season, partly accentuated by winter injury, caused this characteristic to be an insensitive measure of salt, effects on growth; thus, stem growth was not monitored during the second season. After two seasons, all leaves were harvested and plants excavated the week of 17 Aug. 1987, then fresh weights of roots and stems were determined.

Leaf area of 10 to 20 of the youngest, fully expanded leaves from the terminal shoots of plants irrigated with solutions 1 and 3 was measured with a portable area meter (LI-COR 3000; LI-COR, Lincoln, Neb.). For elemental analyses in all salt solutions, all leaves (including petioles) were weighed and washed for successive 5-sec intervals in 1% Liquinox (P-free soap), 0.1 N HCl, and three distilled, deionized water baths (Smith and Storey, 1976). Leaf tissue was dried for 24 hr at 60C, weighed, then ground in a Wiley mill to pass a 40-mesh screen. Pulverized 0.50-g samples were analyzed for K, Na, Ca, and Mg using an inductively coupled Plasma Emission Spectrophotometer (Applied Research Laboratories, Sunland, Calif.) after H_2SO_4-H_2O_2 wet digestion (Parkinson and Allen, 1975). Leaf Cl concentration (0.50-g samples) was determined by coulometric titration (Cotlove, 1963) of hot water extracts (Hanna, 1972) using a chloridometer (Haake Buchler Instruments, Saddle Brook, N.J.). After washing as above, three plants per selection grown with solutions 1 and 3 were separated into the following segments: leaves (including petioles), roots (woody and nonwoody), basal 5 cm of stem (bark and wood separately), and remaining stem portions. These tissues were analyzed for Na, K, Cl, Mg, and Ca as described above.

The analysis of variance (ANOVA) was made by the method of Little and Hills (1978) for a split-plot design with salt solutions as the main plot and rootstock species or selections as subplot, replicated three times. The mean response of six plants per replication represented the experimental unit (subplot) for *P. atlantica* and *P. terebinthus* A, and four plants for the remaining seedlings, making a total of 12 to 18 observations per seedling per saline solution. Mean separation within and between solutions was by Duncan's multiple range test.

Growth data collected at the end of the experiment for *P. atlantica* and *P. terebinthus* A and B were further evaluated by the linear regression method of Maas and Hoffman (1977), which measures crop yield or growth decrease relative to nonsaline controls. The regression allows estimation of the soil salinity threshold. The percent of growth decrease per unit increase in salinity (slope) is also determined, using observations beyond the threshold. For this study, values up to the threshold were

Table 1. Composition and properties of irrigation solutions used in experiment.

Solution	EC[z] ($dS \cdot m^{-1}$)	OP[y] (MPa)	SAR[x]	Solute ($meq \cdot liter^{-1}$) TDC[w]	Na	Ca	Mg	HCO_3	Cl	SO_4
1 (control)	1.4	0.05	4.0	11.5	6.4	4.4	0.7	2.4	4.7	4.4
2	3.4	0.12	9.1	37.8	24.0	9.0	4.8	5.8	12.0	20.0
3	5.8	0.20	14.5	70.0	48.0	12.4	9.6	6.0	24.0	40.0
4	8.0	0.27	18.6	102.0	72.0	15.6	14.4	6.0	36.0	60.0
5	5.8	0.20	4.7	75.3	24.0	30.0	21.3	2.4	24.0	49.0
6	5.8	0.20	14.5	70.0	48.0	12.4	9.6	5.7	36.0	28.3

[z]Electrical conductivity at 25C.
[y]Osmotic pressure by OP = 0.37 $(EC)^{0.96}$, where EC is expressed in $dS \cdot m^{-1}$.
[x]Sodium adsorption ratio.
[w]Total dissolved cations.

Table 2. EC, EC_e, and EC_s (all in $dS \cdot m^{-1}$); and soil solution osmotic pressure (OP_s), sodium adsorption ratio (SAR), and ion concentrations ($meq \cdot liter^{-1}$) at the mean soil water content.

	Characteristics of solutions										
		1986		1987							
Solution	EC	EC_e	EC_s[z]	EC_e	EC_s[z]	OP_s (MPa)	SAR	Na_s[y]	Ca_s	Mg_s	Cl_s
1 (control)	1.4	2.9	4.6	3.7	5.8	0.20	7.7	29	20	8	15
2	3.4	4.4	6.9	7.4	11.7	0.39	18.9	86	24	17	31
3	5.8	6.7	10.6	9.8	15.5	0.51	23.7	121	25	27	48
4	8.0	8.0	12.6	13.0	20.5	0.67	32.0	174	27	32	81
5	5.8	7.1	11.1	9.7	15.2	0.50	10.1	67	29	59	47
6	5.8	7.8	12.3	10.9	17.2	0.56	24.2	128	27	29	83

[z]Estimated as $EC_s = (K)^n EC_e$, where n = 0.89 for all, except for solution 5, where n = 0.87, and K the concentration factor (1.67).
[y]Concentrations in soil solutions at the mean soil water content and estimated by multiplying the concentration factor by the concentrations measured in the saturation extract, except for Ca, where a limit of gypsum solubility was imposed.

Table 3. Effect of EC_s on terminal stem length increase (11 July to 3 Oct. 1986) and root plus stem fresh weight, root fresh weight, and leaf dry weight (measured Aug. 1987).

	Irrigation solution[z]			
Species/selection	1 (Control)	3	4	Mean
		Stem growth (cm)		
Gold II	55.7 a[y]	49.2 a	44.6 a	49.8 a
P. atlantica	41.5 b	35.1 b	33.1 b	36.6 b
P. terebinthus A	25.7 c	13.2 c	12.4 c	17.1 c
P. terebinthus B	12.8 d	7.8 c	10.4 c	10.2 d
P. terebinthus C	16.4 d	9.7 c	8.4 c	11.5 d
		Root + stem fresh wt (g)		
Gold II	468.2 a	294.1 a	173.8 a	312.0 a
P. terebinthus A	175.2 b	95.3 b	61.3 b	110.6 b
P. atlantica	119.2 bc	110.3 b	62.0 b	97.2 b
P. terebinthus B	92.1 c	76.2 b	55.6 b	74.6 b
P. terebinthus C	121.3 bc	72.2 b	66.4 b	86.9 b
		Root fresh wt (g)		
Gold II	192.5 a	139.7 a	73.8 a	135.3 a
P. terebinthus A	96.2 b	65.5 b	37.4 b	66.4 b
P. atlantica	46.3 c	53.5 b	23.3 b	41.0 b
P. terebinthus B	40.2 c	41.9 b	31.6 b	37.9 b
P. terebinthus C	51.4 c	38.0 b	30.2 b	39.9 b
		Leaf dry wt (g)		
Gold II	68.0 a	38.2 a	21.2 a	42.5 a
P. atlantica	13.6 b	12.6 b	6.5 b	10.9 b
P. terebinthus A	14.8 b	7.5 b	4.8 b	9.0 b
P. terebinthus B	10.8 b	6.9 b	4.8 b	7.5 b
P. terebinthus C	9.9 b	6.7 b	5.9 b	7.5 b

[z]Salinity of soil solutions 1, 3, and 4 is indicated in Table 2.
[y]Mean separation by Duncan's multiple range test in columns, $P = 0.05$.

fixed as the maximal growth response according to Maas and Hoffman (1977), except actual data (not percent of control) were plotted. Accurate determination of the threshold using this technique requires multiple observations in the low salinity range (Sooneveld, 1988). Since both the number of treatments and current knowledge of saline resistance of these *Pistacia* spp. in the outdoor environment were limited, the salinity thresholds were approximated by the intersecting regions of the curves.

Results

Soil salinity. Salinity of the soil saturation extract measured in September 1986 (≈11 weeks after the initiation of saline irrigation) ranged from 2.9 to 8.0 $dS \cdot m^{-1}$ (Table 2). When measured in June 1987, soil salinity had increased, then stabilized to the levels shown in Table 2 (average of two readings). The steady salinity levels represent an average increase of 1.95 times the salinity of the irrigation solutions.

Salinity of EC_e does not account for the increase in salinity of soil solutions caused by soil water depletion. Therefore, EC_s at the mean soil water content was related to seedling growth response and was estimated by $EC_s = (K)^n EC_e$, where n = 0.89 (0.87 for solution 5). Individual ion concentrations were estimated by multiplying the concentration factor by the ion concentrations measured in the saturation extract, except for Ca where a limit by gypsum volubility was imposed in all but solution 1. Also included in the table is the osmotic pressure estimated by $OP = 0.37 (EC_s)^{0.96}$ (EC units in $dS \cdot m^{-1}$), which is essentially the numerical expression of a graph given by Campbell et al. (1949).

Stem elongation. The growth increment of all rootstock seedlings, measured on 3 Oct. 1986 (12-week treatment duration), was reduced with irrigation solution 4, on average by 33% from controls (Table 3). The corresponding soil salinity levels are given in Table 2 under 1986. Growth of all species and selections was significantly reduced by this solution, except in *P. terebinthus* B, owing to low vigor at low salt concentration. The higher vigor of Gold II continued throughout the experiment.

Stem and root growth. The combined fresh weight of stem and roots did not decrease until EC_s reached ≈9 to 12 $dS \cdot m^{-1}$, then decreased linearly with increasing EC_s with *r* values ranging from −0.94 to −0.99 (Fig. 1A.) Gold II had the largest weight of stem plus roots of all seedlings with solutions 1, 3, and 4 (Table 3). The water content of stems and roots averaged 0.56 kg/kg fresh weight, irrespective of saline solutions.

Fresh root weights decreased with increasing EC_s (Fig. 1B) in much the same way as root plus stem weight, except that the threshold concentration for reduction was higher (from ≈13 to 14 $dS \cdot m^{-1}$) for roots of *P. atlantica* and *P. terebinthus* B. Gold II produced the largest root mass with solutions 1, 3, and 4, whereas other species and selections produced similar root masses

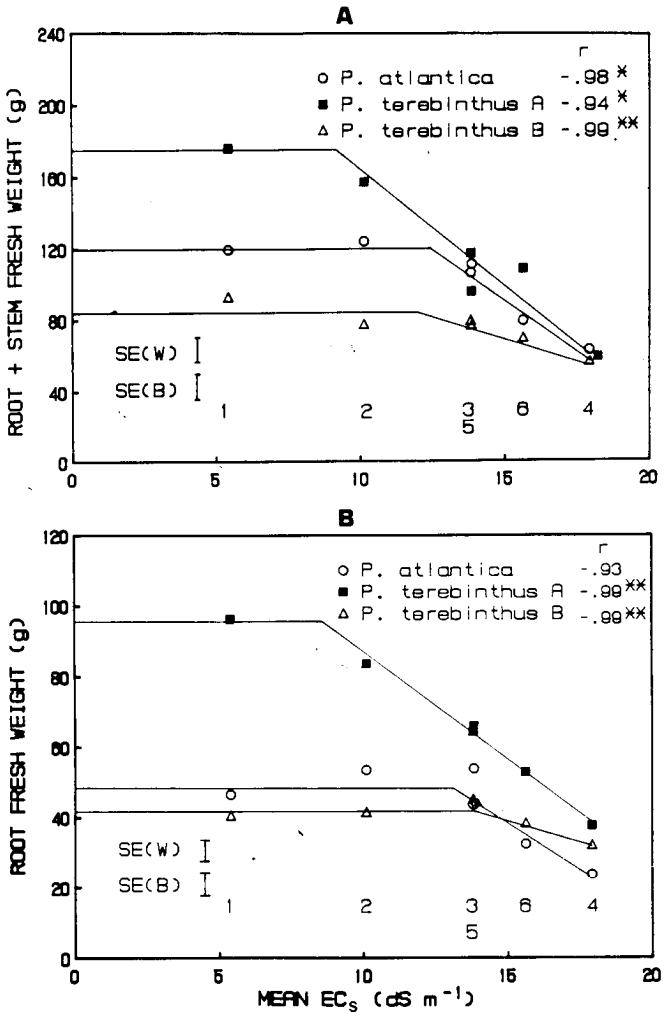

Fig. 1. Effect of EC$_s$ on combined root and stem fresh weight **(A)** and root fresh weight **(B).** The EC$_s$ is shown as the weighted average of 1986 and 1987 season duration. Irrigation solutions (see Table 1) are numbered above abscissa. SE shown for within (W) and between (B) main-plot comparisons. Regression equations for descending portions of curves are: **(A)** *P. atlantica y* = 120 – 11.4 (EC$_s$ – 12.5); *P. terebinthus* A y = 175 – 11.3 (EC$_s$ – 9.5); *P. terebinthus* B y = 85 – 5.3 (EC$_s$ – 12.0). **(B)** *P. atlantica* y = 50 – 6.3 (EC$_s$ – 13.0); *P. terebinthus* A y = 96 – 5.9 (EC$_s$ – 8.5); *P. terebinthus* B y = 44 – 3.1 (EC$_s$ – 13.8).

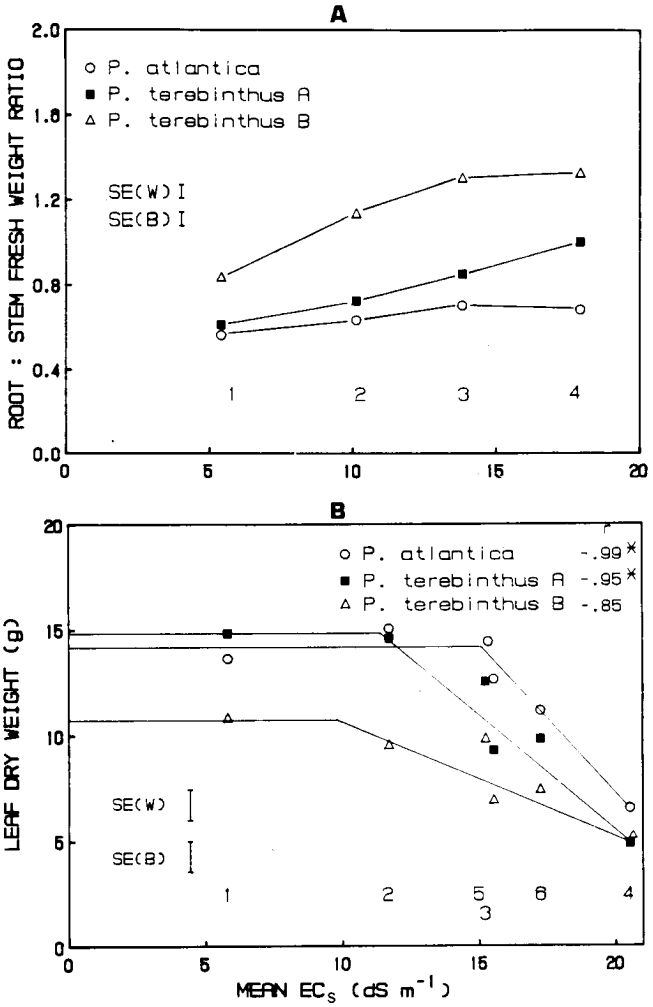

Fig. 2. Effect of EC$_s$ on root : stem fresh weight ratio **(A)** and leaf dry weight **(B).** The EC$_s$ is shown as the weighted average of 1986 and 1987 season durations **(A)** and as the average in 1987 **(B).** Irrigation solutions (see Table 1) and SE are indicated as in Fig. 1. Regression equations for descending portions of curves **(B)** are *P. atlantica* y = 14 – 1.4 (EC$_s$ – 15.0); *P. terebinthus* A y = 15 – 1.1 (EC$_s$ – 11.5); *P. terebinthus* B y = 11 – 0.6 (EC$_s$ – 9.8).

in solutions 3 and 4 (Table 3). Significant main plot reduction in root plus stem weight (all selections combined) occurred with solution 3 (EC$_s$ of 13.8 dS·m^{-1}, and with solution 4 (EC$_s$ of 17.9 dS·m^{-1}) for root weight.

Significant main plot effects for root plus stem and root weights (Fig. 1 A and B) compared favorably to the estimated thresholds for *P. atlantica* and *P. terebinthus* B. For example, main-plot reductions occurred at solutions 3 (Fig. 1A) and 6 (Fig. 1B), which were only marginally greater than the thresholds. The main-plot reduction did not relate as closely to the thresholds of *P. terebinthus* A, which was more sensitive to increasing salinity. The decreasing slopes were less negative for *P. terebinthus* B; however, this selection was the least vigorous both seasons.

All salt treatments increased root to stem fresh weight ratio (Fig. 2A). *P. terebinthus* A and B had significantly higher ratios than *P. atlantica* at solution 4, a result of a greater reduction in shoot weight relative to root weight. Root to stem ratios of Gold II (data not shown) were similar to those of *P. atlantica.*

Leaf dry weight. The salinity thresholds for leaf dry weights ranged from ≈10 to 15 dS·m^{-1}, being highest for *P. atlantica* (Fig. 2B). In spite of the leaf weight reduction, no leaf injuries were observed. There was a greater dispersion of points along the descending portion of this curve, particularly with solutions 3 and 5. However, these differences were not significant. Leaf dry weight (all selections combined) declined significantly at solution 3 (1987 EC$_s$ of 15.5 dS·m^{-1} for main plot reduction). Gold II produced more leaf weight with solutions 1, 3, and 4 (Table 3).

Leaf fresh weight : dry weight ratios were unaffected by solution 3 salinity. Selection averages were 2.74 0.13 and 2.64 ± 0.08 for solutions 1 and 3, respectively. Leaf water content ranged from 0.61 to 0.64 kg/kg fresh weight in both solutions. The leaf size averaged for all rootstock was also unchanged, as average values were 27.4 ± 4.7 and 23.1 ± 3.1 cm^2 for solutions 1 and 3, respectively.

In all growth characteristics except stem elongation, highly

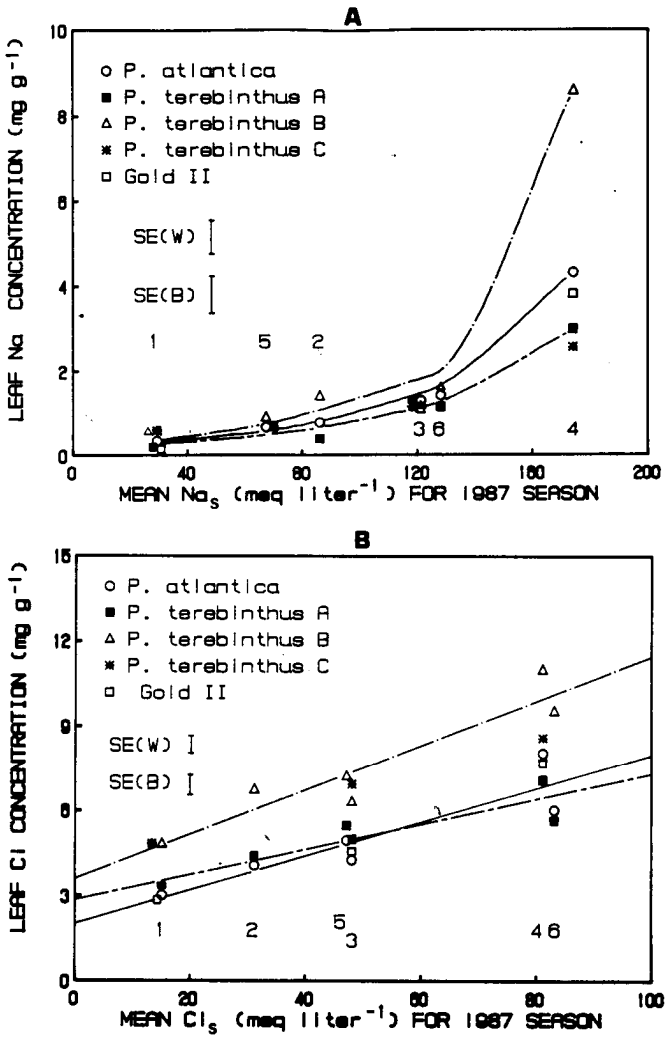

Fig. 3. Effect of soil solution Na and Cl concentrations (Na_s and Cl_s on leaf Na **(A)** and Cl **(B)** concentrations. Data are expressed on a dry-weight basis. Irrigation solutions (see Table 1) and SE are indicated as in Fig. 1. For simplicity, lines for *P. terebinthus* C and Gold II are not connected.

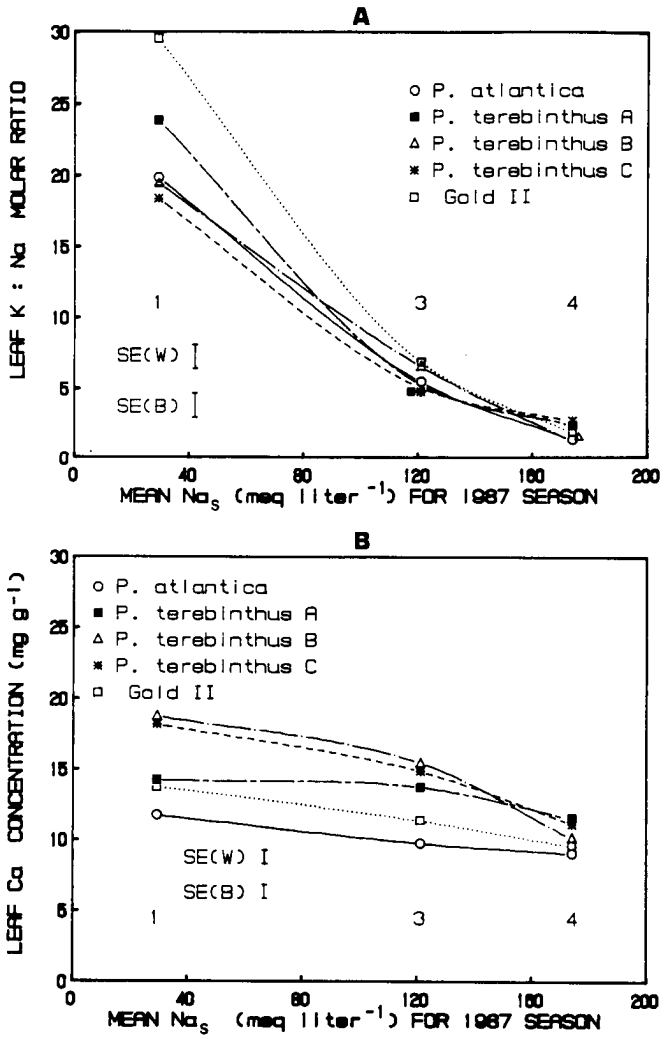

Fig. 4. Effect of Na_s on leaf K : Na ratio **(A)** and Ca concentration (B). Data are expressed on a dry-weight basis. Irrigation solutions (see Table 1) and SE are indicated as in Fig. 1.

significant interaction between solution treatment and species or selection occurred, due to generally higher growth reduction for Gold II than for the other rootstock.

Leaf elemental composition. Leaf Na concentrations did not increase significantly until Na concentrations in soil solutions (NA_s) exceeded 125 meq·liter^{-1} (Fig. 3A). Thereafter, leaf Na concentrations rose sharply, but differed among selections. The highest Na concentration was present in *P. terebinthus* B leaf tissue at the highest Na concentration in soil solutions, whereas leaf Na concentrations of all rootstock were similar with solutions 1 and 3. Leaf Na concentration of *P. atlantica* and *P. terebinthus* A and B was significantly correlated to Na in the six soil solutions, with r values ranging from $^{+}0.83$ to $^{+}0.89$ (in Fig. 3A, best-fit, curvilinear lines were drawn to show the increase in leaf Na concentration >125 meq·liter^{-1} Na in soil solution).

Leaf Cl concentrations increased linearly with increasing Cl concentration in soil solutions (Fig. 3B). *P. terebinthus* B had significantly higher Cl concentrations than the others, and, with the exception of *P. terebinthus* C with solution 3, there were no differences among other selections or species. Leaf Cl concentrations of *P. atlantica* and *P. terebinthus* A and B were highly correlated to Cl concentrations in the six soil solutions ($r = {}^{+}0.92$ to $^{+}0.94$).

Leaf K concentrations (data not shown) of all rootstock (ranging from 9 to 12 mg·g^{-1}) were not affected by increasing salinity. Leaf K : Na ratio declined in proportion to increasing Na_s (Fig. 4A), mainly because of the increase in leaf Na concentration. Gold II had the highest K : Na ratio of all seedlings in the controls.

Rootstock differences were observed for both leaf Mg and Ca concentrations, with higher levels of these ions in *P. terebinthus* leaves in controls. Leaf Ca was lowered significantly by increasing Na_s (Fig. 4B), whereas Mg was unaffected (data not shown).

Ion distribution. Large increases in root Na concentrations compared to the controls were noted in all rootstock with solution 3 (Table 4). *P. terebinthus* B, which had the highest concentration of Na in leaves, had the lowest Na concentration in roots and basal stems. Sodium concentrations in stems increased with salt application but were not affected by rootstock selection or species. Sodium concentrations in the basal stem were similar to those in the remaining stem portion and increased significantly in *P. terebinthus* A and C with solution 3.

Table 4. Concentrations of Na and Cl (milligram per gram of dry weight) in root, main stem, basal 5-cm stem, and bark tissues in solutions 1 and 3.

	Seedling component							
	Roots		Main stem		Basal stem		Bark	
	Irrigation solution[z]							
Species/selection	1	3	1	3	1	3	1	3
				Na (mg·g^{-1})				
Gold II	2.27 a[y]	7.18 a	0.54 a	0.94 a	0.90 a	1.52 a	1.14 b	2.80 b
P. atlantica	3.38 a	7.53 a	0.89 a	1.12 a	0.94 a	0.96 ab	2.26 a	3.25 ab
P. terebinthus A	2.21 a	7.35 a	0.41 a	1.04 a	0.48 a	1.32 a	1.55 ab	3.18 ab
P. terebinthus B	1.87 a	5.03 b	0.58 a	0.72 a	0.42 a	0.42 b	1.86 ab	2.95 b
P. terebinthus C	2.32 a	7.73 a	0.46 a	0.82 a	0.44 a	1.25 a	2.05 ab	3.95 a
				Cl (mg·g^{-1})				
Gold II	1.27 a	2.31 a	0.66 a	0.43 b	0.39 d	0.59 a	1.19 ab	2.25 ab
P. atlantica	1.23 a	1.74 b	0.81 a	0.84 a	0.71 a	0.43 b	1.52 a	2.18 abc
P. terebinthus A	1.04 a	1.25 c	0.55 a	0.67 ab	0.56 bc	0.40 bc	0.91 b	1.62 c
P. terebinthus B	0.88 a	1.11 c	0.75 a	0.75 a	0.45 cd	0.27 c	0.84 b	1.74 bc
P. terebinthus C	1.19 a	1.14 c	0.62 a	0.68 ab	0.65 ab	0.42 b	1.25 ab	2.45 a

[z]Concentration of Na and Cl in soil solutions 1 and 3 is indicated in Table 2.
[y]Mean separation by Duncan's multiple range test in columns, P = 0.05.

No changes occurred in the remaining selections or species. Salinity increased bark Na concentration of all species and selections. Seedlings maintained the highest quantity of Na in roots, particularly in solution 3 (from 72% to 82%). The average quantity of Na in leaves decreased from 12.2% in solution 1 to 7.4% in solution 3, which was accompanied by higher Na storage in roots.

Both concentration and storage of Cl in roots (Table 4) were less than those in leaves. *P. atlantica* and Gold II contained higher Cl concentrations in roots than *P. terebinthus,* and Gold II contained highest basal stem Cl concentrations in solution 3, which declined in the other seedlings. Average basal stem K concentration was lower in this solution (2.1 vs. 3.2 mg·g^{-1} in controls), in addition to having a lower K : Na ratio. However, no changes were noted between solutions 1 and 3 in main stem, root, and bark K concentrations. Also, treatment 3 did not lower Mg and Ca concentrations of nonfoliar portions (data not shown).

Discussion

Significant reduction in stem plus root growth, root growth, and leaf growth (mean response of all rootstock) occurred at EC_e of 13.8, 17.9, and 15.5, or EC_e of 8.7, 11.3, and 9.8 dS·m^{-1} respectively. These threshold values are roughly comparable to the threshold range of *P. vera* top growth (EC_e of 6 dS·m^{-1} and above) observed in 2- to 5-month greenhouse experiments (Sepaskhah and Maftoun, 1981; Sepaskhah et al., 1985). *Pistacia* spp. tested here resisted salinity in excess of *C. illinoensis* seedling rootstock, which expressed leaf injury at EC_e of 8.5 dS·m^{-1} and produced less stem and root weight above EC_e of 3.3 dS·m^{-1} in similar experimental conditions (Miyamoto et al., 1985).

Results shown in Fig. 1 A and B and Fig. 2B did not reveal specific effects of either Na or Cl ions on growth. For example, stem and root weights were similar in solutions 3 and 5. These solutions had similar salinity but over a 2-fold difference in Na : Ca ratio (Table 2). Also, solution 6 contained almost double the Cl concentration of solutions 3 and 5, but growth was reduced in proportion to the salinity increase. EC is directly proportional to osmotic pressure, which exceeded 0.5 MPa in the experiment (Table 2). Sepaskhah and Maftoun (1981) reported an average of 46% growth reduction of *P. vera* seedlings when subjected to a soil matric suction of 0.5 MPa for 11 weeks. Unfortunately, we could find no data for rootstock species.

If an osmotic effect is the primary cause of reduced growth, the selection of rootstocks for saline areas can be based mostly on growth rates in the presence of high salinity. Gold II with vigorous growth characteristics produces larger root mass in the salinity range tested here. *Pistacia* spp. rootstock are typically grown in the orchard for a minimum of one season before budding and thus are exposed to such stress as seedlings, a condition simulated in this study. Of added interest is tree size attainable by use of Gold II, particularly if this rootstock is most influential in controlling compound–genetic tree growth (Rogers and Beakbane, 1957).

There seems to be no substantial difference in growth rates between *P. atlantica* and *P. terebinthus* A with high salt solutions (Table 3), but the growth characteristics are different. *P. atlantica* produces comparatively large leaf mass and top weights, whereas *P. terebinthus* has high root : top ratios, There were no observable differences in root-stem ratios between untreated species and selections. However, the ratios of *P. terebinthus* selections clearly increased with higher salinity, and those of *P. atlantica* and Gold II changed very little (Fig. 2A). Whether this difference exists for budded trees is unknown.

The results given in Figs. 1 and 2 do not imply that specific ion effects should be completely discounted. In this experiment, Cl: SO_4 ratios of irrigation water were ≈ 1:2, except for solution 6. Even though this ratio is the prevailing condition of the Rio Grande Basin, there are certainly sources of water that have much higher Cl : SO_4 ratios. An ongoing greenhouse study indicates that leaves of these rootstock and *P. vera* can be burned in a matter of several weeks when seedlings are exposed to high concentrations (≥60 meq·liter^{-1}) of either $CaC1_2$, $MgCl_2$, or NaCl solutions (unpublished data). In such cases, the selection of rootstock that absorb less Cl should be preferred. Leaf Cl concentrations, however, did not differ greatly among *P. atlantica, P. terebinthus* A, and Gold II (Fig. 3B).

The interpretation of data for Na is more complex than for Cl, but some results we obtained are useful for characterizing responses to Na. Leaf Na concentrations, for example, reached 8 mg·g^{-1} (Fig. 3A), but no leaf injury occurred. This level of Na in seedling leaves of *C. illinoensis* has caused substantial

leaf injury in similar experimental conditions (Miyamoto et al., 1985). Leaves of *Pistacia* spp. are apparently more tolerant to Na than *C. illinoensis.* Also, leaf Na concentrations were only one-third to one-sixth that of *C. illinoensis* leaves at the same concentration range of external Na (Na_s<125 meq·liter^{-1}), indicating that *Pistacia* spp. have comparatively low Na transport characteristics. The fact that leaf K concentration did not decrease with increasing Na_s can also be considered as a resistance feature of *Pistacia* spp. to sodic conditions, although none of the rootstock tested prevented the decline in leaf Ca by increasing Na_s (Fig. 4B).

Another important characteristic of *Pistacia* spp. is the capability to store large quantities of Na in roots. Possibly, shoot Na avoidance (Na exclusion) in *P. terebinthus* B was least effective due to a weaker capability to store the element in roots and basal stems (Fig. 3A and Table 4). Root Na concentrations of the other selections, ranging from 7 to 8 mg·g^{-1} at Na_s of 121 meq·liter^{-1}, were five times those in leaves, which agrees with the findings of Walker et al. (1987). This large storage seems to be adaptive for resistance to Na, even though it complicates the selection of rootstock suitable to sodic conditions. The first complication is the uncertainty involved in the principal plant organ that would be affected by Na. If the adverse effect of Na occurs in roots, the analysis of leaves, as done commonly, may have little direct value in selecting rootstock for sodic areas. If the primary effects are in leaves, a question arises as to the most appropriate time, the concentrations of Na_s, and growth conditions required to make the evaluation. Insufficient duration of experiments, for example, can lead to a premature conclusion that all rootstock exclude Na equally.

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