

# Reassessing the Salinity Tolerance of Greenhouse Roses under Soilless Production Conditions

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**Abstract.** The performance of modern greenhouse-grown roses under intensive nutrient and water management practices questions their traditional classification as a salt-sensitive species, and emphasizes the need to reassess their salinity tolerance. Container-grown 'Bridal Pink' roses (on *R. manetti* rootstock) in a peat moss-based growing medium were irrigated, using moderate leaching fractions (25% targeted, 37.5% actual), with complete nutrient solutions supplemented with NaCl at 0, 5, and 10 mM. These salt concentrations affected the electrical conductivity (EC) and Cl concentrations measured in the leachates, but had no significant effects on flower yield and quality over four growth and flowering flushes (≈29 weeks). Cumulative yields over this period increased an average of ≈13% per leachate EC unit. Thereafter, the applied NaCl concentrations were increased 3-fold to 0, 15, and 30 mM and the plants continued to be evaluated for another four flowering flushes. No significant differences in cut-flower yield and quality were observed among salt treatments despite further increases in leachate EC and Na and Cl concentrations. Symptoms of salt injury were visually observed during the last three flowering cycles, and most heavily on the oldest foliage of plants receiving the highest salt concentration (30 mM), but not on the foliage of harvested shoots. The concentration of most nutrients in leaf tissue was not significantly affected by any of the treatments over the course of the experiment. Leaf Na concentrations were not affected by NaCl applications, averaging 42 mg·kg<sup>-1</sup> across treatments. Conversely, leaf Cl concentrations increased significantly and cumulatively over time with salt additions, and ranged from 1.0 to 17.5 g·kg<sup>-1</sup> (0.1 to 1.75%). Regression analyses revealed that average relative dry weight yields increased with leaf Cl concentrations up to 4.0 g·kg<sup>-1</sup> (0.40%), but were depressed at higher concentrations.

Roses have been traditionally reported to be fairly sensitive to salinity, with appreciable yield losses observed when saturated paste electrical conductivity (EC) exceeds 3 dS·m<sup>-1</sup> (Bernstein, 1964; Bernstein et al., 1972; Davidson, 1969). Such EC levels are easily reached in greenhouse rose production because the crop is irrigated with nutrient solutions (fertigation) that typically range between 1 and 2 dS·m<sup>-1</sup> (Sadasivaiah and Holley, 1973; White, 1987). Reaching high EC levels in soil solution is further exacerbated when using poor quality waters, when practicing minimum leaching, and when recycling leached or run-off solutions (Raviv et al., 1998). Regarding specific ion effects, relatively low Na and Cl concentrations (2–4 mM) in irrigation water have been reported to cause toxicities (Hughes and Hanan, 1978; Yaron et al., 1969).

These reference thresholds to salinity conditions are still in use today despite the fact that

they were developed under crop management conditions that are being phased out and with cultivars that are now obsolete. Traditional soil-grown rose production systems have been replaced by intensively managed soilless and hydroponic systems, along with the use of highly productive cultivars (Bass and van der Berg, 1999; de Kreij and van der Berg, 1990; Raviv et al., 1998; White, 1987). Recent observations from nutrition studies suggest that soilless-grown roses may actually tolerate relatively higher salinities, resulting from high fertility rates, drainage recycling, or both, without significantly, or minimally, affecting flower yield and quality (Bass and van der Berg, 1999; Cabrera, 1992; Cabrera et al., 1993; Raviv et al., 1998).

The objective of this study was to reassess the salinity tolerance of greenhouse roses exposed to increasing NaCl concentrations when grown in soilless media and under intensive fertigation and leaching practices.

## Materials and Methods

Bare-rooted rose plants (*Rosa ×hybrida* 'Bridal Pink' on *R. manetti* rootstock; XX-grade) were planted in 15-L plastic contain-

ers filled with 13-L of a sphagnum peat moss: vermiculite: perlite medium (3:2:1 v/v). The medium had been previously amended with (in kg·m<sup>-3</sup>): 2 dolomitic limestone, 1 CaSO<sub>4</sub>, 0.65 Micromax micronutrient fertilizer and 0.5 triple superphosphate. The containers were spaced at 30-cm centers on a raised bench inside a greenhouse (in New Brunswick, N.J.) with temperatures set at 25°C day/16°C night. High-pressure sodium lamps (SON AGRO 430-W; Philips Lighting Co., Somerset, N.J.) inside the greenhouse were programmed to provide supplementary lighting (700 to 1900 h) when ambient light dropped below 600 μmol·m<sup>-2</sup>·s<sup>-1</sup>. During the establishment phase (26 Aug. to 23 Oct.) the plants were fertigated twice per week with a 20N–4.5P–16.7K fertilizer solution adjusted to provide a N concentration of 100 mg·L<sup>-1</sup>.

Tap water (pH, 7.3; EC, 0.22 dS·m<sup>-1</sup>; Cl<sup>-</sup> at 43 mg·L<sup>-1</sup>, respectively) was used to prepare modified Hoagland nutrient solutions (Hoagland and Arnon, 1950). The base solution composition was (in mM): 8 N (3 NO<sub>3</sub> to 1 NH<sub>4</sub> ratio), 0.5 P (as H<sub>2</sub>PO<sub>4</sub>), 3.0 K, 2.0 Ca, 1.0 Mg, 2.25 S (as SO<sub>4</sub>), and micronutrients were provided at ½ Hoagland concentration. This solution was supplemented with NaCl concentrations of 0, 5, and 10 mM. These initial NaCl concentrations were used during the first half of the experimental period (24 Oct. to 13 May), but were increased to 3× to 0, 15, and 30 mM during the second half (13 May to 15 Nov.).

Five plants were assigned to each solution treatment using a randomized complete-block design. The plants were irrigated on average 2–4 times per week by pumping solutions from 100-L tanks, and delivered through calibrated Chapin spray-stakes (Chapin Watermatics, Waretown, N.Y.) located in each pot. Reference evapotranspiration (ET) was determined gravimetrically in one selected rose plant per treatment, and used to estimate irrigation volumes to apply. Sufficient solution was applied to each treatment to produce a target leaching fraction of 25% (i.e., reference ET volume plus extra 25%). Actual leaching fractions were measured for every single plant in all treatments, by collecting all of their leachate volumes. This was accomplished by employing plant containers having a single drainage hole, which were connected with 1.9-cm-diameter PVC pipe and plastic tubing to individual plastic jugs beneath the greenhouse bench. Leachate volumes were measured gravimetrically and divided by applied irrigation volumes to calculate the actual leaching fractions (expressed on a percentage basis). Leachate solutions were collected once per week and analyzed for pH, EC, and Cl. Chloride concentrations were determined according to Adriano and Doner (1982).

Plants were managed by using conventional pruning practices to produce synchronized flushes of growth/flowering (Cabrera, 1992; Cabrera et al., 1993). Each flush occurred every 6–7 weeks, with eight harvests produced over the 13-month experimental period. Following stem length determination the harvested flower shoots were put into paper bags and oven-dried at 70°C. Dried leaf tissue taken from the middle

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portion of the shoots was ground to pass a 40-mesh screen. Leaf tissue total N and Cl concentrations were monitored for every harvest. Total N was determined using a modified Kjeldahl digestion coupled with N analysis by a diffusion-conductivity method (Carlson et al., 1990) and leaf Cl concentrations were determined according to Gilliam (1971). Leaf tissues from harvests 4 and 8 were subjected to a full nutrient analysis (macro- and micro-nutrients), by using standard ICP spectroscopy procedures (Agricultural Testing Laboratory, Pennsylvania State Univ.).

Plant yield and quality responses to treatments were analyzed by regression and GLM procedures using SAS software (version 8.01, SAS Inst., Cary, N.C.). Regression procedures were also employed to correlate leaf tissue nutrient concentrations to yield. For these latter regressions the yield data was converted to relative dry mass values, which allowed the combination of results from all harvest events into a single function (without compounding the absolute yield differences between individual harvest events throughout the year). This was accomplished by identifying the treatment (mean value) with the highest dry mass within each flowering flush and assigning it a value of 100, which was then used to calculate the relative value for the other treatment means within that flush.

**Results and Discussion**

**Dry mass and flower yields.** During the first half of the experiment it became readily apparent that the applied NaCl concentrations of 0, 5, and 10 mM had no significant effects on the flower and dry weight yields in any of the individual harvest events (H1-H4, Table 1) or on a cumulative basis (data not shown). This was unexpected as leachate analyses showed a definitive effect of the salt treatments on the EC and Cl concentrations existent in the soil solution (Fig. 1). Roses are reported to be fairly sensitive to soil solution EC values >3 dS·m<sup>-1</sup> (Bernstein et al., 1972; White, 1987), and Na and Cl concentrations higher than 2–4 mM (Hughes and Hanan, 1978; Yaron et al., 1969). These thresholds were exceeded in the first phase of the experiment. Average leachate EC and Cl concentrations for this period were 2.2, 3.7, and 4.3 dS·m<sup>-1</sup>, and 5.5, 15.1, and 17.3 mM, respectively, for plants receiving 0, 5, and 10 mM NaCl applications (Fig. 1).

Cumulative dry weight yields over this experimental period were positively and significantly correlated with average leachate EC (Fig. 2A). The average yield increase of ≈13% per unit EC observed in the 2–5 dS·m<sup>-1</sup> range in this study contrasts the 2% to 7% yield losses per leachate EC unit reported in rockwool-based hydroponic rose production systems under similar EC ranges (Baas and van der Berg, 1999; De Kreij and van der Berg, 1990). It is hypothesized that the cation exchange capacity (CEC) of the peat : vermiculite growing medium used in the present experiment may have played a role in the maintenance of balanced nutrient conditions that would otherwise not be found

Table 1. Yield components of ‘Bridal Pink’ roses grown at different NaCl levels over eight flowering flushes.

NaCl (mM)	Harvest event							
	H1 <sup>a</sup> 13 Dec.	H2 2 Feb.	H3 23 Mar.	H4 7 May	H5 19 June	H6 31 July	H7 14 Sept.	H8 4 Nov.
<i>Dry weight yield (g/plant)</i>								
0	20	27	40	51	55	47	53	34
5/15	30	30	47	60	47	43	55	31
10/30	27	31	52	62	61	40	49	27
<i>Flowers per plant</i>								
0	5.6	4.6	4.6	6.0	6.2	7.2	6.0	6.0
5/15	7.4	5.4	5.4	5.2	6.8	6.4	6.0	5.4
10/30	7.0	5.2	5.8	5.8	6.0	6.0	5.4	5.6
<i>Stem length (cm)</i>								
0	42	52	57	54	54	46	46	44
5/15	46	49	60	57	53	41	48	41
10/30	42	54	59	56	52	40	45	36

<sup>a</sup>No significant treatment trends (regressions) or differences (analysis of variance) were detected for the evaluated yield components in any harvest event.

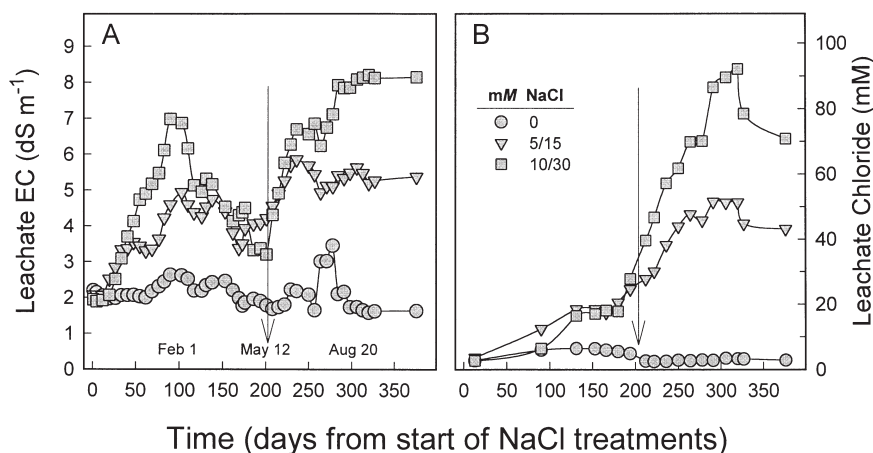


Fig. 1. (A) Electrical conductivity and (B) chloride concentrations in leachates from ‘Bridal Pink’ roses irrigated with complete nutrient solutions having different NaCl concentrations. Arrows indicate time when NaCl concentrations were increased to 3× (see text). Each data point represents the mean of five plants.

under a somewhat chemically inert rockwool medium.

The observed yield responses to the applied NaCl concentrations during these first four harvest events led to a decision to increase the salt stress level (i.e., NaCl rates) to 3×, and continue evaluating yields for another four harvest cycles. These higher NaCl rates produced further increases in leachate EC and Cl concentrations, averaging 2.1, 5.3, and 7.0 dS·m<sup>-1</sup>, and 2.9, 43.0, and 69.8 mM, respectively for plants receiving 0, 15, and 30 mM NaCl applications during this experimental period (Fig. 1). Despite these higher salinity rates, once again no significant differences in yield

parameters were detected for individual harvests (H5-H8; Table 1) or cumulatively (data not shown) during this second half of the experiment. Cumulative dry weight yields over this period with higher salinity levels showed no obvious response to leachate EC as high as 8.9 dS·m<sup>-1</sup> (Fig. 2B). This once again contradicts previous reports of yield losses under lower salinities in rockwool hydroponic systems (Baas and van der Berg, 1999; De Kreij and van der Berg, 1990). These observations lend further support to the contention that CEC of peat : vermiculite growing medium used in the present experiment may have conferred a nutrient buffering effect that minimizes the

Table 2. Salt burn ratings for foliage of ‘Bridal Pink’ roses grown at different NaCl concentrations.

NaCl (mM)	Rating dates <sup>z</sup>			
	29 July	28 Aug.	19 Sept.	4 Nov.
0	1.0	1.0	0.9	0.6
5/15	1.3	1.2	1.2	1.6
10/30	1.6	2.4	2.8	3.4
Response	NS	L**	L*	L***

<sup>z</sup>Salt burn rating based on a scale from 0 to 5, where 0 = best, no salt burn damage and 5 = worst, highest salt burn damage.  
<sup>ns, \*, \*\*, \*\*\*</sup>Nonsignificant or significant at *P* ≤ 0.05, 0.01, or 0.001, respectively; L = linear (n = 15).

salinity conditions that would otherwise be operating in a minimally buffered rockwool hydroponic system.

Despite the lack of yield response to the higher NaCl concentrations during the latter four harvest cycles, visual symptoms of salt injury became apparent during the last three flowering cycles (Table 2), and more severely in the oldest foliage of plants receiving the highest salt concentration (30 mM). Symptoms included the typical scorching and necrosis around the leaf margins, extending to the whole laminae over time and leading ultimately to leaf drop. Salt damage symptoms were not observed, however, in the foliage of the harvested flower shoots that were all considered of marketable quality. Furthermore, no plant died over the course of the experiment. While this observation may seem remarkable, we projected that a longer exposure period to the 30 mM NaCl salinity level would eventually cause rose plant death. Bernstein et al. (1972) and Fernández Falcón et al. (1986) have reported complete defoliation, rose plant death, or both, at similar or higher salinities under shorter exposure times for plants growing in mineral (field) soils.

Irrigation management, growing medium properties and environmental factors can significantly affect plant responses to salinity (Bernstein et al., 1972). While a moderate leaching fraction (LF) of 25% was targeted for the plants in this study, the observed LF average across treatments was a higher 37.5% ( $\pm 2.3\%$  SE). This leaching fraction regime could have contributed to the observed rose plant salt tolerance, particularly during the second part of the experiment when the NaCl concentrations were raised to 3 $\times$ . Significant yield increases have been reported for 'Royalty' roses when LF is increased from 25 to 50% under the typical range of ECs found under commercial, non-saline, growing conditions (2.0 to 4.5 dS $\cdot$ m $^{-1}$ ; Cabrera et al., 1993).

*Leaf tissue nutrient status and correlation with yields.* A complete nutrient analysis of leaf tissue from harvests 4 and 8 did not reveal any major changes or disorders in leaf concentrations of most macro- and micronutrients with respect to the applied NaCl treatments (Table 3).

Leaf Na concentrations were not significantly affected by any of the NaCl treatments over the course of the experiment, averaging 42 mg $\cdot$ kg $^{-1}$  dry weight (Table 3). The lack of leaf tissue Na accumulation with increases in NaCl salinity suggests the existence of a noteworthy exclusion mechanism. This finding is supported by the detailed nutritional studies of Sadasivaiyah and Holley (1973) who also reported an apparent Na exclusion ability in leaf tissue of 'Forever Yours' roses budded on *R. manetti*, the same rootstock used in the present experiment. These results, however, do not offer any leads as to where in the plant (leaf, stems-trunk, or roots) this putative Na exclusion mechanism may be operating. Fernández-Falcón et al. (1986) observed significant leaf Na accumulations (as high as 4800 mg $\cdot$ kg $^{-1}$ ) in rose plants of 'Mercedes' on *R. canina* 'Inermis' irrigated with solutions containing Na as high as 16 mM. These observations and data from other rose

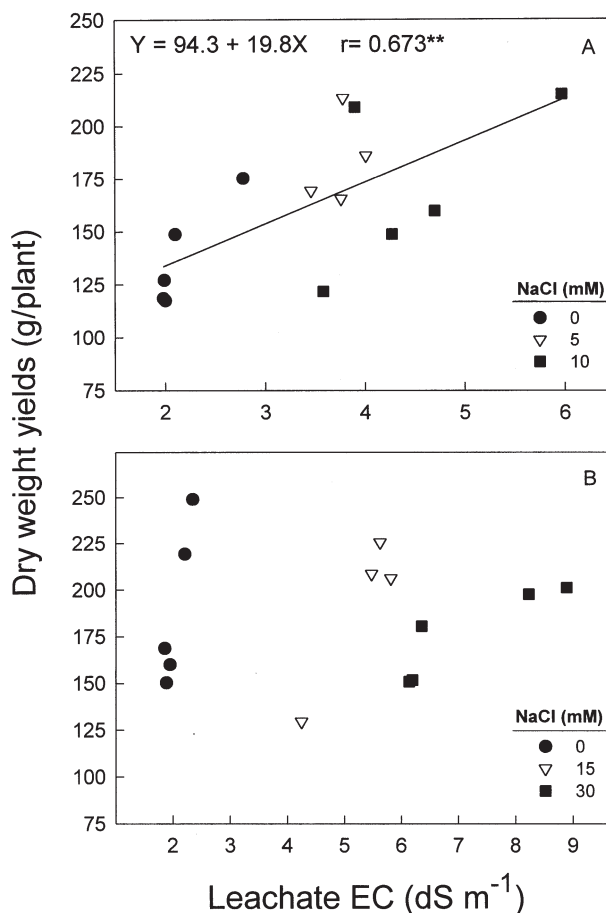


Fig. 2. Cumulative dry weight yields of 'Bridal Pink' roses in relation to leachate electrical conductivities (EC). The plants were irrigated over four flowering cycles with complete nutrient solutions supplemented with 0, 5, and 10 mM NaCl (A). Thereafter, the NaCl concentrations were increased to 3 $\times$  (see text), and the plants evaluated for another four flowering cycles (B). Each data point represents an individual plant

salinity studies (Bernstein et al., 1972; Hughes and Hanan, 1978; Yaron et al., 1969), would suggest that Na exclusion may be influenced by rootstock selection. Such observations warrant the evaluation of different scion/rootstock combinations to elucidate the origin of this apparent Na exclusion ability.

Leaf Cl concentrations increased significantly with NaCl application rates, and cumulatively over time, ranging from 1.0 to 17.5 g $\cdot$ kg $^{-1}$  (0.1% to 1.75%) (Fig. 3). This is consistent with results from previous rose

salinity studies (Bernstein et al., 1972; Hughes and Hanan, 1978; Yaron et al., 1969). These results indicate that the scorching and salt burn damage observed in the older foliage of plants receiving the highest NaCl applications (Table 2) was due to Cl accumulation and not Na. This same observation was made by Bernstein et al. (1972) when exposing 'Grenoble' roses budded on 'Dr. Huey' rootstock to various Na and Cl salts.

The literature on rose nutrition does not report a range of Cl or Na levels considered

Table 3. Leaf tissue nutrient concentrations for two flowering flushes in 'Bridal Pink' roses grown with different NaCl levels.

NaCl (mM) <sup>a</sup>	Macronutrients (% dry wt)					Micronutrients (mg $\cdot$ kg $^{-1}$ )				
	N <sup>b</sup>	P	K	Ca	Mg	B	Mn	Fe	Zn	Na
<i>Harvest 4 (7 May)</i>										
0	3.75	0.45	2.08	1.75	0.25	40	163	68	82	38
5	3.68	0.43	2.14	1.73	0.28	46	176	67	82	35
10	3.89	0.44	2.21	1.72	0.28	44	188	68	81	36
<i>Harvest 8 (4 Nov.)</i>										
0	2.82	0.25	2.29	1.29	0.23	43	155	46	30	44
15	2.87	0.27	2.22	1.22	0.22	38	132	46	29	46
30	2.72	0.27	2.29	1.25	0.24	40	122	51	34	50

<sup>a</sup>Original NaCl applications (Harvests 1 to 4) were increased to 3 $\times$  for the second half of the experimental period (Harvests 5 to 8; see text for details).

<sup>b</sup>No significant treatment trends (regressions) or differences (analysis of variance) were detected for any of these nutrients.



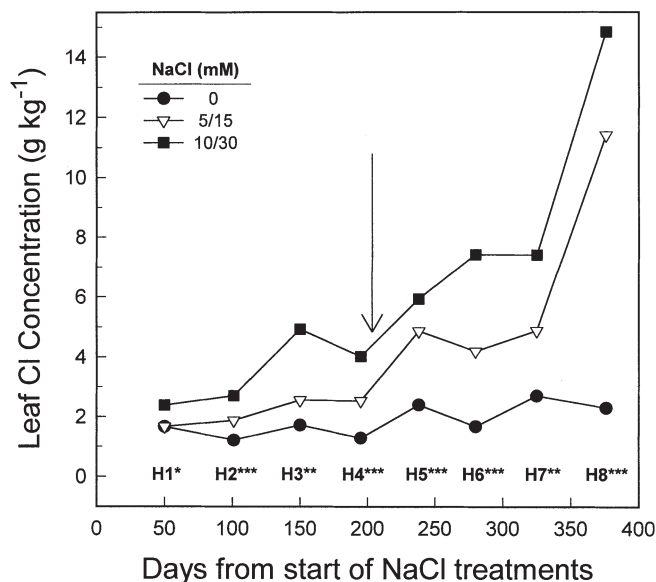


Fig. 3. Leaf tissue chloride concentrations in 'Bridal Pink' roses irrigated with complete nutrient solutions having different NaCl concentrations. Leaf samples were taken from harvested flower shoots over eight flushes of growth and flowering. Arrow indicates time when NaCl concentrations were increased to 3 $\times$  (see text). The letter H followed by a number represents flower harvest event, and the symbols \*,\*\*,\*\*\* denote significance at  $P \leq 0.05$ , 0.01, and 0.001, respectively. Each data point represents the mean leaf Cl concentration of five plants.

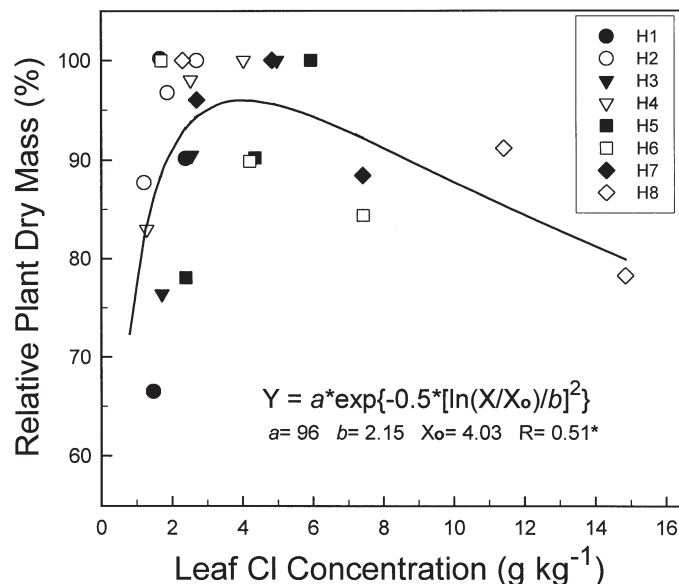


Fig. 4. Relative dry mass yields of 'Bridal Pink' roses in relation to leaf tissue Cl concentration. The letter H followed by a number represents flower harvest event. The regression model is a log normal peak equation ( $P = 0.045$ ). Each data point represents the mean of five plants.

adequate or optimum for flower yield and quality. Further, there is the implied notion that Cl and Na should be avoided whenever possible. This contrasts with the widely recognized categorization of Cl and Na as, respectively, essential and beneficial plant mineral nutrients (Marschner, 1995). In an effort to identify an 'optimum' or adequate Cl status (i.e., accumulation or concentration) in roses, the mean relative yield data from each individual harvest and treatment were correlated against their respective average leaf Cl nutrient concentrations. A regression analysis revealed that the relative rose dry weight yields increased significantly and positively with leaf tissue Cl concentrations up to 4.0 g $\cdot$ kg $^{-1}$  (0.40%) but were significantly depressed at higher concentrations (Fig. 4). This is a remarkable observation from the standpoint of placing this "optimum" rose leaf Cl concentration in the macronutrient range. While it has been reported that most salt sensitive woody species, like fruit trees, present toxicity symptoms when leaf Cl exceeds 3.5 g $\cdot$ kg $^{-1}$  (Marschner, 1995), some species like kiwifruit (*Actinidia deliciosa*) have high Cl requirements with established leaf Cl critical deficiency contents of  $\approx 2.0$  g $\cdot$ kg $^{-1}$  (Smith et al., 1987). Furthermore, the apparent positive effect of moderate leaf Cl concentrations on dry weight yield, as suggested by the regression analysis (Fig. 4), suggest that greenhouse rose productivity could actually benefit from moderate Cl concentrations in the irrigation water or in the nutrient solutions used to irrigate them.

The results from this study bring into question the historic classification of roses as salt-sensitive species, particularly under

current greenhouse management conditions. The apparent tolerance of roses to the NaCl salinity conditions in this study, along with the observations of leaf Na exclusion and positive effects of moderate leaf Cl concentrations on dry weight yields justify the need for further research. Future research should include a closer look at the effect of scion : rootstock interactions on these phenomena.

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