Characterizing Salinity Limits of New Guinea *Impatiens* in Recirculating Subirrigation

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ABSTRACT. New Guinea *impatiens* (*Impatiens hawkeri* Bull.) were grown in a recirculating ebb-and-flow subirrigation system under increasing levels of salinity stress from a mixture of NaCl and CaCl₂ (1:1 equivalent ratio, 2:1 molar ratio) and recommended production levels of other nutrients. Growth and quality decreased as salinity level increased, with a 75% to 80% growth reduction at 18 mol·m⁻³ NaCl–CaCl₂ compared to controls. Among controls, root mass distribution was 10%, 50%, and 40% in the top, middle, and bottom layers of the root zone, respectively. In the highest salinity treatment (18 mol·m⁻³ NaCl–CaCl₂), most of the root mass was in the middle layer (80%), while the root mass in the top and bottom layers was reduced to 5% and 15%, respectively. The electrical conductivity (EC) of the growing medium was high in the top layer in all treatments, but only exceeded maximum recommended levels in the middle and bottom layers in the 4-mol·m⁻³ or higher treatments. Initial postproduction leaching caused the salts in the top layer to migrate to the middle and bottom layers, which in some experiments induced a rapid and transient wilting. Up to six leaching and drying cycles of a 0.20 leaching fraction were required to reduce EC in all layers to recommended levels. Overall, salable plants of good quality and size were produced with up to 2 mol·m⁻³ (total 152 mg·L⁻¹) NaCl–CaCl₂ in the recirculated nutrient solution.

Environmental issues, such as water quality and conservation, are at the forefront of public concerns, and it appears that more regulations concerning water management will be a result of this movement. Whether out of personal concern for the environment, cost efficiency, or concerns over increasing governmental regulations, many growers are recognizing the need to modify their production habits (Reed, 1996; Skimina, 1996).

Traditional cultural practices used to produce greenhouse crops have encouraged the constant use of water-soluble fertilizers coupled with excess leaching to prevent the accumulation of salts in the root zone (Biernbaum, 1992; Molitor, 1990). Fertilizer runoff can contribute to nitrate contamination of water resources (Biernbaum, 1992).

Recirculating ebb-and-flow subirrigation systems are viable solutions for growers interested in limiting fertilizer runoff and preserving clean water sources (Reed, 1996). These closed systems allow complete recycling of solutions while reducing water use by as much as 40% to 70% compared to conventional drip or sprinkler irrigation systems. However, supplies of high-quality water are becoming less available to producers of greenhouse crops, and in many areas growers are forced to irrigate plants with water of higher salinity (Lieth and Burger, 1989). These salts can be very damaging to crops as they accumulate in the soil or growing medium in which the plant is growing. Lack of leaching in a closed system leads to high salt buildup in the root zone (Kent and Reed, 1996; Molitor, 1990), and using poor-quality water will intensify this effect.

The objective of our research was to determine the effects of saline irrigation water in a recirculating ebb-and-flow subirrigation system on the growth and development of a salt-sensitive greenhouse crop.

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Materials and Methods

EXPERIMENT 1. Vegetative terminal stem cuttings were taken from stock plants of *Impatiens hawkeri* 'Barbados' (Paul Ecke Ranch, Encinitas, Calif.) on 18 May 1994 and placed under intermittent mist. After 21 d, rooted cuttings were transplanted into 11-cm-diameter pots using a sphagnum peat and perlite-based growing medium amended with dolomitic limestone, gypsum, and a wetting agent (Sunshine Mix no. 2; Sun Gro Horticulture, Inc., Bellevue, Wash.). Trace elements were supplied by using a complete micronutrient formulation of Micromax (Grace-Sierra, Milpitas, Calif.) at the recommended rate of 1 kg·m⁻³.

The experiment was conducted in a glass greenhouse equipped with evaporative cooling beginning on 17 June 1994 and terminating on 8 Sept. 1994 for 12 weeks total cropping time. Temperature averaged 32/25 °C day/night, relative humidity averaged 80%, and average noontime light intensity was 441 μmol·m⁻²·s⁻¹.

The experiment was a completely randomized design that contained 20 plants per treatment and a total of eight salinity concentrations. Each treatment was placed in separate subirrigation trays (Midwest Growers, St. Charles, Ill.), which were randomized at four trays per bench. Each tray was connected to an individual collection tank for recirculating its solution. Soil tensiometers (model M; Irrometer Co., Inc., Riverside, Calif.) were

Table 1. Composition of treatment solutions used in subirrigation studies. The NaCl–CaCl₂ were present in a 1:1 equivalent ratio (2:1 molar ratio).

NaCl–CaCl ₂		Na	Ca	Cl
(mol·m ⁻³)	(mg·L ⁻¹)	(mg·L ⁻¹)	(mg·L ⁻¹)	(mg·L ⁻¹)
0	0	0	0	0
2	153	31	27	95
4	303	61	53	189
6	456	92	80	284
8	608	123	107	378
10	760	153	134	473
14	1063	214	187	662
18	1368	276	241	851

placed in an extra pot (with plant) per treatment and the trays were flooded manually at 25 ± 3 kPa. Irrigating at 25 kPa is within the moisture tension range of peat-based media that yields excellent growth without water stress (Karlovich and Fonteno, 1986). Trays were flooded to a depth of 2 to 3 cm for 10 to 20 min, depending on time of year and time required for the medium to become fully saturated. All treatments received a nutrient solution that contained $8 \text{ mol}\cdot\text{m}^{-3}$ N, $1.5 \text{ mol}\cdot\text{m}^{-3}$ P, and $2 \text{ mol}\cdot\text{m}^{-3}$ K made from $4 \text{ mol}\cdot\text{m}^{-3}$ NH_4NO_3 , $0.4 \text{ mol}\cdot\text{m}^{-3}$ K_2HPO_4 , $1.1 \text{ mol}\cdot\text{m}^{-3}$ KH_2PO_4 , and $0.05 \text{ mol}\cdot\text{m}^{-3}$ K_2SO_4 according to Kent and Reed (1996). Combinations of NaCl and CaCl_2 in a 1:1 equivalent ratio (2:1 molar ratio), were used to provide varying levels of salinity to each treatment at total salt concentrations of 0, 2, 4, 6, 8, 10, 14, 18 $\text{mol}\cdot\text{m}^{-3}$ NaCl- CaCl_2 (Table 1). Many studies have long used combinations of Na, Ca, and Cl to impose salinity stress (Richards, 1954). All solutions were made using water purified by reverse osmosis (RO).

After each irrigation, samples of the solution were taken from each nutrient holding tank and monitored for pH and electrical conductivity (EC). The nutrient solution remained clear and its pH and EC did not change significantly over time. The volume of nutrient solution was replenished with fresh solution when the volume remaining was insufficient to flood trays.

Five plants were randomly selected for harvest from each treatment every 3 weeks (days 21, 42, 63, and 84) until termination of the experiment. Plant height, shoot and root fresh and dry mass, leaf area, leaf number, and flower number were recorded. For leaf area, harvested leaves were laid flat between sheets of newspaper and placed in a drying oven at 54°C for 24 h, and then dry leaf area was measured using an area meter (Delta T Devices, Cambridge, England). Dry leaf area was $86\% \pm 1\%$ of fresh leaf area (Kent and Reed, 1996).

The root zone was divided into three horizontal layers (≈ 3 to 4 cm each), yielding a top-third, a middle-third, and a bottom-third of the growing medium. A sample of growing medium was collected from each layer and the medium was air dried. The growing medium EC and pH were determined by using a 1:2 dilution method (Warncke and Krauskopf, 1983) and measured with a conductivity meter (model 44600; HACH Co., Loveland, Colo.) and a pH meter (model 701A; Orion Research, Inc., Cambridge, Mass.) with a pH electrode (M708; Markson Science, Inc., Phoenix, Ariz.). For harvesting roots, the roots were separated from the growing medium of each layer by hand with gentle

washing on a screen under a steady stream of tap water. Roots were blotted dry with paper towels, root fresh mass was recorded, the roots were placed in a drying oven at 54°C for at least 24 h, and then root dry mass was measured and recorded.

EXPERIMENT 2. 'Illusion' and 'Blazon' New Guinea impatiens (Mikkelsen, Ashtabula, Ohio) were grown to determine differences in salt tolerance using the same experimental design as Expt. 1. 'Illusion' was reported to be salt sensitive while 'Blazon' was reported to be salt tolerant (Dave Hartley, Paul Ecke Ranch, Encinitas, Calif., personal communication). Haver and Schuch (1996) reported that 'Blazon' was more tolerant to high growing medium EC than 'Illusion' when grown with controlled-release fertilizers and no leaching. The experiment began 22 Nov. 1994 and terminated 31 Jan. 1995 for 70 d total cropping time. Temperature averaged $30/17^\circ\text{C}$ day/night, and average noontime light intensity was $552 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$. Destructive harvests and general growth observations were made at days 42 and 70.

EXPERIMENT 3. New Guinea impatiens 'Illusion' and 'Blazon' were grown under the same conditions and salt treatments as in the first experiment. The experiment began 21 Mar. 1995 and terminated 5 June 1995 for 76 d total cropping time. Noontime temperature averaged 30°C and light intensity averaged $698 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$. A quality rating was performed at the end of the production cycle by five judges on 20 plants per treatment. Plants were judged on vigor, foliage color and quality, and open flowers, with a rating of 5 = excellent and 1 = dead or severely stunted; 4 and 5 were deemed salable. Then the plants were leached six consecutive times and the leachate was collected and measured for EC. Leaching was accomplished by slowly pouring RO water onto the growing medium surface until a 0.20 leaching fraction was obtained. The growing medium was allowed to dry, as in a normal irrigation cycle, between leachings. Growing medium EC for the three root-zone layers was determined, as described in Expt. 1, before leaching and then after the first, second, fourth, and sixth leaching-drying cycle.

Results and Discussion

EXPERIMENT 1. Maximum growth of plants occurred in the control treatment ($0 \text{ mol}\cdot\text{m}^{-3}$ salts). There was a significant decrease in all growth measurements (height, shoot fresh mass, total leaf area, area per leaf, and root dry mass) with increasing salt concentration (Table 2). Visual symptoms of salt stress included wilting of leaves, dull foliage color, and reduced flower number.

Table 2. The effect of eight salinity levels on growth response of New Guinea impatiens 'Barbados' at final harvest (day 84) in a recycled subirrigation system (Expt. 1). Data represent means of five replications.

NaCl- CaCl_2 treatment ² ($\text{mol}\cdot\text{m}^{-3}$)	Ht (cm)	Growth measurement			
		Shoot fresh mass (g)	Total leaf area (cm^2)	Area per leaf (cm^2)	Root dry mass (g)
0	23.3	149	874	2.9	2.9
2	19.3	105	605	2.6	2.2
4	17.6	65	384	2.3	1.3
6	16.7	68	441	2.1	1.4
8	16.8	62	395	2.0	1.3
10	12.8	27	179	1.6	0.6
14	13.8	37	200	1.6	0.9
Significance	***	***	***	***	***
LSD ($\alpha = 0.05$)	1.7	14	198	0.5	0.4

²The $18\text{-mol}\cdot\text{m}^{-3}$ salt treatment is not included due to death of the plants.

***Significant at $P < 0.001$ by ANOVA.

Fig. 1. Shoot dry mass of New Guinea impatiens 'Barbados' grown at various levels of NaCl–CaCl₂ (1:1 equivalent ratio, 2:1 molar ratio) for 84 d in a recirculating subirrigation system (Expt. 1). Bars indicate standard error of the mean.

Necrosis on leaf tips and margins appeared at the higher salt concentrations. Up to day 21, there was very little difference between the shoot dry mass of plants in the various treatments (Fig. 1). At days 42, 63, and 84, shoot dry mass decreased sharply from the control level to the 4-mol·m⁻³ treatment. At final harvest (day 84), shoot dry mass in the 10- to 18-mol·m⁻³ treatment levels decreased by as much as 75% to 80% compared to the control. Judd and Cox (1992) also found a significant reduction in shoot dry mass of top-watered New Guinea impatiens with increasing fertilizer concentration and increasing growing medium EC.

Growing medium EC was higher in the top layer of the root zone compared to the middle and bottom layers and increased with increasing salt treatment. EC of the control reached as high as 1.7 dS·m⁻¹ in the top layer, while the EC of the middle and bottom layers reached a high of 0.59 dS·m⁻¹. In the 4-mol·m⁻³ treatment, where growth was significantly reduced at day 42 (Fig. 1), EC of the middle and bottom layers was 2.2 and 0.96 dS·m⁻¹, respectively. Kent and Reed (1996) found that top-layer EC was not a detrimental factor in growth of subirrigated New Guinea impatiens at N concentrations as high as 30 mol·m⁻³, and that growth was not detrimentally affected as long as EC levels of the middle and bottom layers did not exceed 1.25 dS·m⁻¹ (1:2 extraction). However, Haver and Schuch (1996) demonstrated good growth and quality of 'Blazon' and 'Illusion' at growing medium EC of 1.8 and 2.5, respectively, when grown with controlled-release fertilizer and no leaching, assuming the moisture level of the medium was maintained at a high level.

The initial pH of the growing medium was 6.5. In the 0-salt controls, the pH decreased slightly over time, and at harvest the pH of the top layer was still 6.5, the pH of the middle layer averaged 6.0, and the pH of the bottom layer averaged 5.5. Similar results were reported by Kent and Reed (1996). With increasing NaCl–CaCl₂ concentration, the pH decreased from an initial of 6.5 to ≈5.2, but with little difference between the layers.

EXPERIMENT 2. There were no observable differences in growth between 'Illusion' and 'Blazon'. The higher salt tolerance of 'Blazon' reported by Haver and Schuch (1996) and D. Hartley (personal communication) was not observed. As in Expt. 1, maximum growth was observed in the control with a gradual decrease in growth response as the concentration of NaCl–CaCl₂ increased (Fig. 2). Leaf area was representative of the overall growth observed. Maximum leaf area was observed in the 0- to 4-mol·m⁻³ salt treatments, and there was a greater reduction in leaf area at salt levels >6 mol·m⁻³ (Fig. 3). Reduced leaf area is a common response to saline irrigation water (Talaesnik, 1987; Taylor et al., 1987; Wannamaker and Pike, 1987). Yelanich and Biernbaum (1993) found leaf area decreased with increasing fertilizer concentration in top-irrigated and subirrigated plants.

The root-to-shoot ratio remained constant between the control and the 8-mol·m⁻³ treatment. This is because root and shoot dry mass decreased in a similar fashion between the control and the 8-mol·m⁻³ treatment. The equal sensitivity of roots and shoots to moderate salinity is similar to that reported for coleus (*Coleus Blumei* Benth) and salvia (*Salvia splendens* F. Sellow ex Roem. & Schult.) (Ibrahim et al., 1991). The root-to-shoot ratio decreased between the 8- and 18-mol·m⁻³ treatment. This is because there was a 73% reduction in root dry mass and only a 40% reduction in shoot dry mass between the 8- and 18-mol·m⁻³ treatment. The decrease in root mass at the higher salinity treatments was due to root death toward the end of the experiment as evidenced by an average 0.35 g dry root mass in the 18-mol·m⁻³ treatment at day 42, but an average 0.15 g dry root mass at day 70. The shoot system had yet to reflect the root damage at end of the experiment.

Distribution of roots within the container was determined by measuring root mass in the top, middle, and bottom layers of the growing medium (Fig. 4). In the control, root mass was highest in the middle and bottom layers, which contained 50% and 40% of the total root mass, respectively. The top layer contained only 10% of the root mass. In the high-salinity treatments (18 mol·m⁻³), 80% of the total root mass was localized in the middle layer. The bottom layer and top layer contained only 15% and 5% of the root mass, respectively. Kent and Reed (1996) observed a similar distribution

Fig. 2. New Guinea impatiens 'Illusion' grown at various levels of NaCl–CaCl₂ (1:1 equivalent ratio, 2:1 molar ratio) in a recirculating subirrigation system at day 70 (Expt. 2).

Fig. 3. Leaf area of New Guinea impatiens 'Blazon' and 'Illusion' grown at various levels of NaCl-CaCl₂ (1:1 equivalent ratio, 2:1 molar ratio) in a recirculating subirrigation system at days 42 and 70 (Expt. 2). Bars indicate standard error of the mean.

Fig. 4. Percentages of the root dry mass recovered in the top, middle, and bottom layers of the growing medium of New Guinea impatiens 'Illusion' grown at 0 and 18 mol·m⁻³ NaCl-CaCl₂ (1:1 equivalent ratio, 2:1 molar ratio) in a recirculating subirrigation system at day 70 (Expt. 2). Bars indicate standard error of the mean.

of roots in subirrigated New Guinea impatiens in which root dry mass was highest in the middle, then bottom, then top layer at increasing N concentrations.

EXPERIMENT 3. The quality rating at the end of the experiment showed that 'Illusion' was salable when grown in the 0- to 4-mol·m⁻³ salts range, while 'Blazon' was only deemed of salable quality when grown at the 0-mol·m⁻³ salt level (Fig. 5). Plant quality decreased as salt concentration increased above these levels.

When subirrigated plants were leached (0.2 leaching fraction) by top watering at the end of the experiment, EC of the leachate increased with the first and second leaching cycle, and then leachate EC generally declined with subsequent leachings (Fig. 6). Before leaching, EC of the growing medium was highest in the top layer (Fig. 7a). After the first and second leaching cycles, growing medium EC decreased in the top layer and increased slightly in the

Fig. 5. Quality rating for New Guinea impatiens 'Illusion' and 'Blazon' grown at various levels of NaCl-CaCl₂ (1:1 equivalent ratio, 2:1 molar ratio) in a recirculating subirrigation system at day 64 (Expt. 3). Ratings were 5 = excellent, 4 = good, 3 = fair, 2 = poor, and 1 = dead, with 4 and 5 deemed salable plants. Bars indicate standard error of the mean.

Fig. 6. Electrical conductivity of the leachate collected after six leaching and drying cycles (0.20 leaching fraction each cycle) of New Guinea impatiens 'Blazon' grown at various levels of NaCl-CaCl₂ (1:1 equivalent ratio, 2:1 molar ratio) in a recirculating subirrigation system (Expt. 3).

middle and bottom layers (Fig. 7b). By the fourth and sixth leaching cycle, EC of the growing medium in all layers decreased (Fig. 7c). This indicated that with top watering, salts in the top layer became soluble and moved downward and that multiple leachings are necessary to remove salts from the root zone. Argo and Biernbaum (1995) also found that applying a 0.20 leaching fraction to surface-irrigated poinsettias (*Euphorbia pulcherrima* Willd. ex Klotzsch) at the end of the production cycle did not completely remove fertilizer salts that had accumulated in the top layer of the root zone. Instead, salts moved gradually into the lower portion of the root zone and acted as a continuous source of nutrients to the plant after fertilization had ceased.

After the first and second leaching, the plants exhibited a rapid (30 min) wilting (Fig. 8). If the plants were brought indoors, they quickly recovered. Similar wilting was not observed among control plants. This indicates that the wilting was probably a response to high transpirational demand in the greenhouse (the experiment

Fig. 7. Growing medium electrical conductivity of top, middle, and bottom layers of the root zone of New Guinea impatiens 'Illusion' grown at various levels of NaCl-CaCl₂ (1:1 equivalent ratio, 2:1 molar ratio) in a recirculating subirrigation system (Expt. 3) (A) before leaching, (B) after one leaching cycle (0.20 leaching fraction each), and (C) after 6 leaching and drying cycles (0.20 leaching fraction each). Bars indicate standard error of the mean.

Fig. 8. Postproduction transient wilting of New Guinea impatiens 'Blazon' within 1 h after the second leaching cycle (0.2 leaching fraction each). Plants were grown at various levels of NaCl-CaCl₂ (0, 2, and 4 mol·m⁻³) in a recirculating subirrigation system for 64 d (Expt. 3).

was terminated June 5) and the increase in EC in the middle and bottom layers upon initial leaching (Fig. 7b). The association between transient wilting and top watering was not consistent in all experiments and was not observed in experiments conducted during the milder seasons of the year (winter), but occurred only under stressful environments (summer).

In summary, acceptable growth and quality of plants were ob-

served under moderate salinity stress up to 2 mol·m⁻³ (152 mg·L⁻¹) NaCl-CaCl₂ added to the recirculating subirrigation solution. Salinity >2 mol·m⁻³ NaCl-CaCl₂ caused progressively decreased growth and quality. Given the experimental design and data collected, we cannot determine if the damage was due to general salinity effects between the roots and the rhizosphere (osmotic stress, altered nutrient uptake, etc.), nutrient-ionic imbalances within the plant (Ca-Mg, Na-K, etc.), or specific ionic toxicities (Na, Cl). The EC of the top layer of the growing medium increased above recommended levels, even at 2 mol·m⁻³ NaCl-CaCl₂. This did not pose a problem in production, but caused transient wilting during summer months upon postproduction leaching due to salts moving down into the active root zone. Several leaching and drying cycles at a 0.20 leaching fraction were required to remove the accumulated salts effectively.

Literature Cited

- Argo, W.R. and J.A. Biernbaum. 1995. Root-medium nutrient levels and irrigation requirements of poinsettias grown in five root media. *HortScience* 30:535-538.
- Biernbaum, J.A. 1992. Root-zone management of greenhouse container-grown crops to control water and fertilizer use. *HortTechnology* 2:127-132.
- Haver, D.L. and U.K. Schuch. 1996. Production and postproduction performance of two New Guinea *Impatiens* cultivars grown with controlled release fertilizer and no leaching. *J. Amer. Soc. Hort. Sci.* 121:820-825.
- Ibrahim, K.M., J.C. Collins, and H.A. Collin. 1991. Effects of salinity in growth and ionic composition of *Coleus blumei* and *Salvia splendens*. *J. Hort. Sci.* 66:215-222.
- Judd, L.K. and D.A. Cox. 1992. Growth of New Guinea impatiens inhibited by high growth-medium electrical conductivity. *HortScience* 27:1193-1194.
- Karlovich, P.T. and W.C. Fonteno. 1986. Effect of soil moisture tension and soil water content on the growth of chrysanthemum in 3 container media. *J. Amer. Soc. Hort. Sci.* 111:191-195.
- Kent, M. and D.W. Reed. 1996. Nitrogen nutrition of new guinea impatiens 'Barbados' and *Spathiphyllum* 'Petite' in a recirculating subirrigation system. *J. Amer. Soc. Hort. Sci.* 121:816-819.
- Lieth, J.H. and D.W. Burger. 1989. Growth of chrysanthemum using an irrigation system controlled by soil moisture tension. *J. Amer. Soc. Hort. Sci.* 114:387-392.
- Molitor, H.D. 1990. Bedding and pot plants: The European perspective with emphasis on subirrigation and recirculation of water and nutrients. *Acta Hort* 272:165-171.
- Reed, D.W. 1996. Closed production systems for containerized crops: Recirculating subirrigation and zero-leach systems, p. 221-245. In: D.W. Reed (ed.). *Water, media, and nutrition for greenhouse crops*. Ball Publishing, Batavia, Ill.
- Richards, L.A. (ed.). 1954. *Diagnosis and improvement of saline and alkaline soils*. USDA Agr. Hdbk. no. 60.
- Skimina, C.A. 1996. Total nursery recycling systems, p. 247-262. In: D.W. Reed (ed.). *Water, media, and nutrition for greenhouse crops*. Ball Publishing, Batavia, Ill.
- Taleisnik, E. 1987. Salinity effects on growth and carbon balance in *Lycopersicon esculentum* and *L. pennellii*. *Physiol. Plant.* 71:213-218.
- Taylor, R.M., L.B. Fenn, and C.A. Pety. 1987. Nitrogen uptake by grapes with divided roots on differentially salinized soils. *HortScience* 22:664.
- Wannamaker, M.J. and L.M. Pike. 1987. Onion responses to various salinity levels. *J. Amer. Soc. Hort. Sci.* 112:49-52.
- Warncke, D.D. and D.M. Krauskopf. 1983. *Greenhouse growth media: Testing and nutrition guidelines*. Michigan State Univ. Coop. Ext. Ser. Bul. E-1736.
- Yelanich, M.V. and J.A. Biernbaum. 1993. Root-medium nutrient concentration and growth of poinsettia at three fertilizer concentrations and four leaching fractions. *J. Amer. Soc. Hort. Sci.* 118:771-776.