Effects of Fertilizer Concentration and Minimum-leach Drip Irrigation on the Growth of New Guinea Impatiens

Harvey J. Lang¹ and Timothy R. Pannkuk²

Department of Horticultural Sciences, Texas Agricultural Experiment Station, Texas A&M University, College Station, TX 77843-2133

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Abstract. New Guinea impatiens ‘Barbados’ (*Impatiens* *×hawkeri*) were fertilized with solutions containing N at 6, 12, or 18 mmol·L⁻¹ delivered from a drip irrigation system with either minimum leaching or standard leaching (0.3 to 0.4 leaching fraction). Irrigation was monitored and controlled by computers using microtensiometers placed in representative pots of each treatment. In two separate experiments, growth index, fresh mass, and dry mass were dependent upon both fertilizer concentration and irrigation treatment. Maximum growth overall was achieved at 12 mmol·L⁻¹ N regardless of irrigation treatment; however, standard-leached plants receiving N at both 6 and 18 mmol·L⁻¹ produced larger plants than did similarly fertilized minimum-leached plants. Leaf scorch, spotting, or marginal necrosis did not occur in any of the treatments. Leaf N, P, and K concentrations were highest in plants treated with N at 18 mmol·L⁻¹, but Ca, Mg, and several micronutrients were highest in plants at 6 mmol·L⁻¹ N. At the end of the cropping period for both experiments, growing medium electrical conductivity (EC) in the uppermost one-third layer of the pot was two to four times as high as that in the bottom two-thirds (root zone) layer. Root-zone EC ranged from 0.6 to 4.0 dS·m⁻¹ and increased as fertilizer concentration increased. Standard leaching had little effect in reducing root-zone EC except in plants fertilized with N at 18 mmol·L⁻¹. All plants continued to perform well and flower after 4 weeks in a simulated interior environment. Minimum-leach drip irrigation used ≈35% less solution than did standard irrigation with leaching, and eliminated N runoff.

Extensive use of water and fertilizers in the production of greenhouse crops is an increasing concern for growers due to the rising costs of these production inputs and the potential for both point-source ground and surface water contamination. Fertilizer and water application in greenhouse production is greater than in any other area of agricultural crop production (Molitor, 1990). Nitrogen fertilizer recommendations for greenhouse potted plants range from 1500 to 2500 kg·ha⁻¹·year⁻¹ (Joiner et al., 1981). These rates are ≈15 to 25 times as great as those recommended for many agronomic field crops and represent a significant production cost and potential source of nitrate pollution.

Several strategies have been developed, including the use of controlled-release fertiliz-

ers (CRFs), irrigation recycling, and minimal leaching, to try to reduce fertilizer and water use and minimize fertilizer runoff (Biernbaum, 1992). Controlled-release fertilizers release nutrients gradually during the growth of the crop and reduce leaching of nutrients from the media of container-grown plants (Cox, 1993; Rathier and Frink, 1989). A major disadvantage of using CRFs, however, is the loss of fertilizer control and management by the grower once the CRF has been incorporated into the growing media. Subirrigation and irrigation solution recycling effectively reduce fertilizer use and runoff in comparison with conventional overhead sprinkler and drip irrigation systems (Dole et al., 1994; Kent and Reed, 1996; Yelanich and Biernbaum, 1993). However, these systems require a significant capital investment that must be recovered by labor savings or higher value crops, and therefore are not a viable option in many greenhouse operations.

One low-cost method to reduce fertilizer and water use in containerized crop production is to reduce leaching. A major concern in minimal leaching systems is the accumulation in the growing medium of soluble salts that can adversely affect plant growth. Ku and Hershey (1991) grew poinsettias (*Euphorbia pulcherrima* Willd. ex Klotzsch) at 21 mmol·L⁻¹ N with leaching fractions (LFs) ranging from ≈0 to 0.4 and found no significant differences in height, fresh mass, or dry mass between the different irrigation treat-

ments, although electrical conductivity (EC) levels in the lower third of the medium were much greater with the lower LFs. Conversely, studies by the same researchers with geraniums (*Pelargonium* *×hortorum* L.H. Bailey) using a similar fertilizer concentration resulted in much poorer growth at the lower LFs (Ku and Hershey, 1992). Consequently, differential salt tolerance by many crop species apparently determines the degree of success of minimal leaching irrigation regimes. Yelanich and Biernbaum (1993) showed that growth of poinsettia was dependent upon both LF and applied fertilizer concentration. They found that fresh mass and shoot : root ratio were similar when 7 mmol·L⁻¹ N and 0.15 LF or 14 mmol·L⁻¹ N and 0.55 LF were used. High-quality plants can be grown with minimal runoff by maintaining the moisture level in the medium constant at a level high enough to keep soluble salts from significantly reducing the water potential (Haver and Schuch, 1996; Kiehl et al., 1992; Pannkuk and Lang, 1993). Constant moisture tensions in the medium can be monitored and maintained using microtensiometers linked to a computer-controlled irrigation system (Lieth and Burger, 1989).

New Guinea impatiens is an important crop that has gained popularity for both indoor and outdoor landscape plantings. Until recently, water and fertilizer requirements for this species have not been well documented. Using conventional overhead irrigation, Judd and Cox (1992) reported that maximum growth was achieved using a fertilizer concentration of 7 mmol·L⁻¹ N at every irrigation, and maintaining EC levels below 1.5 dS·m⁻¹ in the growing medium. New Guinea impatiens grown in an ebb and flow subirrigation system performed best at ≈8 mmol·L⁻¹ N (Kent and Reed, 1996). Haver and Schuch (1996) studied the interaction of CRF and irrigation regime for New Guinea impatiens grown in a no-leach system. They found that both shoot and root dry mass were highest when commercially recommended rates of incorporated CRF were used at relatively high moisture tension levels (–1 to –3 kPa) in the growing medium. We know of no published studies on the optimum fertility regime for New Guinea impatiens grown with minimum-leach drip irrigation using conventional water-soluble fertilizers. The objectives of this study, therefore, were to compare fertility rates for New Guinea impatiens in both a standard conventional leach and a minimum-leach drip irrigation system, and to evaluate the effects of these treatments on total fertilizer use, media salt accumulation, and plant growth.

Materials and Methods

New Guinea impatiens ‘Barbados’ plugs (Paul Ecke Ranch, Encinitas, Calif.) were potted into 11-cm-wide × 10-cm-tall (550 cm³) round, plastic pots (one plant per pot) filled with 1 sphagnum peat : 1 horticultural grade perlite (by volume) amended with dolomitic limestone and gypsum. Each pot was carefully packed to ensure uniform bulk density among the pots, and plants were irrigated initially

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¹Assistant Professor; to whom reprint requests should be sent.

²Research Assistant.

with reverse osmosis (RO) water using overhead, hand irrigation before beginning the experiment. Two experiments were conducted. Expt. 1 began on 17 Dec. 1993 and ran for 10 weeks, while Expt. 2 began on 23 Sept. 1994 and ran for 9 weeks. Plants were grown in a glass greenhouse with average noontime photosynthetically active radiation (PAR) of 550 (Expt. 1) or 600 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ (Expt. 2) and average temperature of 26 °C day/18 °C night (Expt. 1) or 27/20 °C (Expt. 2).

Plants were arranged in a factorial design with three blocks and 15 plants (reps) per treatment combination per block. Treatments consisted of three fertilizer concentrations (6N-1.5P-2K, 12N-3P-4K, or 18N-4.5P-6K $\text{mmol}\cdot\text{L}^{-1}$) and two irrigation regimes (minimum leach and standard leach). Nitrogen was supplied in a ratio of 45% NH_4^+ :55% NO_3^- . All fertilizer solutions contained the following nutrients ($\mu\text{mol}\cdot\text{L}^{-1}$) prepared in RO water: Mg (250), S (250), B (18.5), Fe (17.9), Mn (9.1), Zn (2.3), Cu (1.6), and Mo (1.0). All 15 plants of a particular treatment were placed in a 63 × 110-cm plastic subirrigation tray (Midwest Growmaster, St. Charles, Ill.) and irrigated using drip irrigation.

To characterize moisture retention in the medium and determine irrigation tension setpoints, a moisture release curve was constructed. Four samples of growing medium were uniformly packed in aluminum cylinders (7.5 × 7.5 cm) placed in modified Buchner filter funnels, each containing a ceramic porous plate. Plexiglass plates with an opening on top for the air pressure source were used to form an airtight seal on the funnels. Each sample of medium was saturated with water for 48 h and the excess water drained, then pressure was applied in increments for 24 h at a time. Outflow water was recorded for each of eight moisture tensions ranging from 0 to 65 kPa. After the last pressure increment, samples were oven-dried for 24 h at 105 °C and dry mass and volume recorded. Data were plotted and fitted using a nonlinear regression model (Milks et al., 1989) (Fig. 1).

For irrigation of the plants in each tray, moisture tension in the growing medium was monitored and controlled with GEM III computer software and solid-state electronic microtensiometers (Q-Com Corp., Irvine, Calif.). Individual treatments were monitored by placing a microtensiometer in the center of a representative pot of that treatment, with the ceramic tip ≈ 5 cm from the bottom of the pot. Each tray's drip irrigation system consisted of 15 plastic microtubes (0.15-cm i.d.) fitted with lead emitters attached to a plastic header (1.9-cm i.d.). Each header was attached to a submersible pump (0.33 h.p.) placed in a 70-L plastic tank. The drip irrigation systems were carefully calibrated to ensure that solution was applied slowly and uniformly across and within each treatment. For the minimum-leach treatments, plants were irrigated automatically when the tension in the medium reached -4.5 kPa (tension when the medium felt dry to the touch), and indicating a total moisture content ≈ 30% (Fig. 1). Irrigation was stopped when the representative microtensiometer in the me-

Fig. 1. Moisture release curve calibrated for a 1 peat : 1 perlite (by volume) medium. Regression equation is $Y = 41/[1 + (0.60X)^{1.92}]^{0.48} + 14$, $r^2 = 0.99$.

dium detected a moisture tension of -0.1 kPa. This endpoint tension resulted in an effective water-holding capacity (Elliott, 1992) where little, if any, leaching occurred (estimated <2 mL leached per container per irrigation). For plants in the leach treatments, moisture tensions were checked several times per day, and when a reading of -4.5 to 5.0 kPa was observed, the plants were irrigated semiautomatically for 5 min. This 5-min cycle provided a LF ranging from ≈ 0.3 to 0.4. Total solution use over the entire production period for each fertilizer × irrigation treatment was determined. For the leach treatments, runoff was collected from each tray and samples were analyzed colorimetrically for nitrate (Cataldo et al., 1975), nitrite (Keeney and Nelson, 1982), and ammonium (Hinds and Lowe, 1984).

Plants and media were harvested from each treatment periodically during the production period. For Expt. 1, two plants were harvested from each treatment combination block bi-weekly, while three plants were harvested every 3 weeks in Expt. 2. Plants were evaluated for overall appearance and quality, then height, width, number of open flowers, number of lateral stems, and shoot and root fresh and dry mass were recorded. From each harvested plant, the growing medium was divided horizontally into an upper one-third layer and bottom two-thirds layer and dried for 48 h at 37 °C. Electrical conductivity and pH for each medium sample were determined using a modified saturated media extract (SME) method (Warncke, 1986) with measurements taken directly in the filtered extract. At the final harvest, leaf disc tissue samples were collected from each of the five most recently expanded leaves from each plant, and were analyzed for chlorophyll using the method of Moran (1982) and Moran and Porath (1980). In Expt. 1, additional whole leaf samples were harvested from each plant, washed with a nonionic detergent followed by three rinses with RO water, and then dried for 72 h at 60 °C.

Dried samples were ground to pass through a 20-mesh screen, sent to a commercial plant testing laboratory, and analyzed for nutrients using macro Kjeldahl and inductively coupled plasma (ICP) spectrometry. Plant and media data were analyzed for variance at each harvest time using the SAS GLM procedure, treating fertilizer concentration and irrigation regime as classification variables (SAS Institute, Cary, N.C.). Regression analysis was also used on plant growth data when determining responses to fertilizer concentration.

Results and Discussion

Plant growth. At the completion of both experiments, all treated plants were of marketable quality and size, healthy, and floriferous. There were no obvious signs of plant nutrient deficiencies or toxicities, or of salt damage. Plants continued to perform well and flower after 4 weeks in a simulated interior environment. Analysis of variance for both experiments indicated that there was a significant interaction between fertilizer concentration and irrigation method for overall growth index, and total plant fresh and dry mass (Table 1). While the standard leached treatments produced the largest plants at both 6 and 18 $\text{mmol}\cdot\text{L}^{-1}$ N, minimum-leach irrigation at 12 $\text{mmol}\cdot\text{L}^{-1}$ N resulted in plants that were equal to or larger than those that were leached. There were no significant interactions between fertilizer concentration and irrigation method for the number of lateral stems or flowers, or for leaf chlorophyll content, although plants in Expt. 2 that were leached had slightly more flowers than those under minimum-leach treatments (data not shown). There was also a main effect of fertilizer on chlorophyll concentration of plants in Expt. 1, with plants having greater chlorophyll levels at 6 $\text{mmol}\cdot\text{L}^{-1}$ N than at higher fertilizer concentrations (data not shown).

Our findings suggest that both fertilizer

Table 1. Effects of fertilizer concentration and irrigation treatment on various growth parameters of New Guinea impatiens 'Barbados' after 10 (Expt. 1) or 9 (Expt. 2) weeks of cropping.

Treatment		Expt. 1			Expt. 2		
Nitrogen (mmol·L ⁻¹)	Leaching	Growth index [†] (cm ²)	Fresh mass [‡] (g)	Dry mass [‡] (g)	Growth index (cm ²)	Fresh mass (g)	Dry mass (g)
6	Minimum	486	108.9	9.2	413	82.3	8.2
	Standard	640	149.3	12.2	697	146.7	12.1
12	Minimum	656	151.2	12.4	770	171.1	13.1
	Standard	650	151.8	12.6	717	169.4	12.8
18	Minimum	468	99.2	8.2	536	109.7	8.9
	Standard	547	129.0	10.1	561	121.6	9.6
Significance							
Fertilizer concn (C)		*	*	*	*	*	*
Irrigation (I)		*	*	*	*	*	*
C × I		*	*	*	*	*	*

[†]Growth index = height × [(width 1 + width 2)/2].

[‡]Total of both shoots and roots.

*Significant at $P \leq 0.05$ using analysis of variance.

concentration and volume applied need to be considered when establishing fertilizer rates for New Guinea impatiens. Although irrigation method did not affect the growth of plants at 12 mmol·L⁻¹ N, it did have an effect at both 6 and 18 mmol·L⁻¹ N (Table 1). Ku and Hershey (1992) found that geraniums grown under various LFs and irrigated with relatively high fertilizer concentrations (N at 21 mmol·L⁻¹) produced the largest plants, with LFs between 0.2 to 0.4. In our experiments, New Guinea impatiens fertilized with N at 18 mmol·L⁻¹ were larger when leached with a 0.3 to 0.4 LF than when minimum-leached. Studies with poinsettias grown under subirrigation (no leaching) have indicated that fertilizer rates should be reduced compared to overhead irrigation where leaching is practiced (Dole et al., 1994; Yelanich and Biernbaum, 1993). Over the range of fertilizer concentrations used in our studies, regression analysis indicated a significant polynomial growth response to fertilizer concentration under both irrigation methods (data not shown). The r^2 values for dry-mass accumulation vs. fertilizer concentration in both experiments ranged from 0.62 to 0.68, with peak accumulation occurring around 12 mmol·L⁻¹ N. For New Guinea impatiens, we recommend that fertilizer application at relatively high concentrations (18 mmol·L⁻¹ N) be avoided in a minimum-leach, drip irrigation system; however, under the conditions of these tests, concentrations should not be reduced much below 12 mmol·L⁻¹ N because growth will probably be reduced. Other factors, such as the environment and overall growth potential of the crop, will undoubtedly influence nutrient uptake rates and should be considered in selecting application rates. This may help explain differences reported in the literature regarding optimum fertilizer rates and associated dry-mass accumulation in New Guinea impatiens grown under various irrigation methods (Judd and Cox, 1992; Kent and Reed, 1996). Further studies are needed with additional fertilizer treatments under different environmental conditions to determine the actual optimum concentration in a minimum-leach system. Our findings in this study, however, parallel studies using various rates of CRF with no-leach irrigation (Haver and

Schuch, 1996). In those studies, a moderate (vs. a higher or lower) rate of CRF produced the greatest growth of New Guinea impatiens in media with moderately high moisture levels.

Tissue analysis. As with the measured growth parameters, there was a significant interaction between applied fertilizer concentration and irrigation regime on tissue nutrient concentrations (Table 2). Higher N-P-K fertilizer rates resulted in higher tissue N, P, and K, and lower Ca and Mg concentrations in the plant; however, nutrient uptake was partially dependent upon the type of irrigation treatment used. While treatment with 6 mmol·L⁻¹ N resulted in slightly higher N, P, and K concentrations in standard leached than in minimum-leached plants, tissue N, P, and K levels were greater in minimum-leach treatments at higher fertilizer rates. One possible explanation is that the larger volumes of fertilizer solution used in the standard leach treatments at 6 mmol·L⁻¹ N improved solution saturation of the growing medium, and consequently allowed for greater nutrient uptake. Argo and Biernbaum (1994) have shown that in a subirrigation system, the amount of water-soluble fertilizer to which a plant is exposed in an entire crop cycle is a function of both the number of fertilizer applications and the volume of solution held in the medium. Under minimum-leach treatments at higher fertilizer rates, however, solution volume did not appear to be limiting, and N, P, and K quickly

began to build up in the medium. This probably resulted in greater plant nutrient tissue concentrations than in similarly fertilized plants that were leached. In recent studies using gravel culture, uptake of N, P, and K by New Guinea impatiens increased significantly when these nutrient concentrations were increased in solution from the range of 2N-0.5P-0.5K to 16N-4P-3.5K mmol·L⁻¹ (Mankin and Fynn, 1996).

Levels of other tissue nutrients, such as Ca, Mg, Fe, and Zn, were also uniquely affected by both fertilizer concentration and irrigation, but in a manner much different from N, P, and K (Table 2). Leaf tissue concentrations were significantly higher in plants irrigated with lower rates of N-P-K fertilizer. In this case, plant uptake of these nutrients was apparently being strongly depressed by application of relatively high concentrations of other major cations, such as NH₄⁺ and K⁺ (Marschner, 1995). This might have caused some of the nutrients, particularly Ca and Mg, to become growth-limiting, especially at the highest fertilizer concentration. Standard leaching generally produced plants with lower concentrations of Ca, Mg, Fe, and Zn; however, there was little difference in tissue concentrations of these elements between the two irrigation treatments at 18 mmol·L⁻¹ N.

Media analysis. A significant stratification of salts into upper and lower layers of the pot occurred shortly after experiments began (Figs. 2 and 3). After 2 weeks, EC levels in the upper one-third layer were already some two to four times as great as in the bottom two-thirds layer. Overall salt accumulation was lower in Expt. 2 (Fig. 3), perhaps because of the shorter cropping period or increased plant nutrient demand. (Plants were generally larger at the end of the cropping cycle in Expt. 2 than in Expt. 1.) Analysis of variance revealed that both fertilizer concentration and irrigation treatment had a significant effect on EC at the completion of both experiments. However, there was significant interaction between these factors for each of the segregated medium layers. While there was little difference in EC in the upper layer at either 6 or 12 mmol·L⁻¹ N for either irrigation method (Figs. 2 A and C, 3 A and C), there were significantly higher salt concentrations in the minimum-leach treatments at 18 mmol·L⁻¹ N (Figs. 2 E and 3 E).

Table 2. Effects of fertilizer concentration and irrigation treatment on leaf tissue nutrient concentrations of New Guinea impatiens 'Barbados' after 10 weeks of cropping in Expt. 1.

Treatment		Nutrients									
Nitrogen (mmol·L ⁻¹)	Leaching	N	P	K	Ca	Mg	Fe	Mn	Zn	B	Cu
		(% dry mass)					(μg·g ⁻¹ dry mass)				
6	Minimum	4.72 [‡]	0.78	2.66	1.83	0.40	372	115	107	76	14
	Standard	4.95	0.82	3.11	1.63	0.32	337	87	99	74	15
12	Minimum	6.35	0.94	3.90	1.06	0.25	331	98	108	74	13
	Standard	5.72	0.90	3.65	0.81	0.21	290	86	78	66	12
18	Minimum	7.33	0.94	5.00	0.71	0.17	303	97	80	75	12
	Standard	6.80	0.91	4.81	0.67	0.18	310	83	82	67	11
Significance											
Fertilizer concn (C)		*	*	*	*	*	*	*	*	NS	NS
Irrigation (I)		NS	NS	NS	*	*	*	*	*	NS	NS
C × I		*	*	*	*	*	*	NS	*	NS	NS

[‡]Mean for six plants.

NS, Nonsignificant or significant at $P \leq 0.05$, respectively, using analysis of variance.

Similar interaction between fertilizer rate and irrigation was evident in the lower layer of the pot; however, differences were not as great as in the upper layer.

Salt stratification in the growing medium has been documented in several studies using both subirrigation (Argo and Biernbaum, 1994; Kent and Reed, 1996) and overhead irrigation systems (Argo and Biernbaum, 1995; Haver and Schuch, 1996; Ku and Hershey, 1991, 1992; Yelanich and Biernbaum, 1993). Evaporation of water from the top layer of the pot drives the salts from the root zone to the surface of the medium. In our studies, stratification occurred in both standard leached and minimum-leached treatments and across all fertilizer treatments; however, differences in EC between the two layers was greater at higher fertilizer rates. Although EC level was extremely high in the uppermost layers of the medium, it did not appear to inhibit growth, since there were few roots growing in this area. Salt accumulation in both layers of the pot was similar for both irrigation treatments at 6 mmol·L⁻¹ N, indicating that leaching did not appear to move a significant amount of salts out of the root zone. At higher fertilizer rates, however, root-zone EC levels were lower in the standard leach treatments than in the minimum-leach treatments. These findings support reports of others (Ku and Hershey, 1991; Yelanich and Biernbaum, 1993) that higher LF_s resulted in lower root-zone EC levels under moderate- to high-fertilizer treatments. Other factors, such as the use of poor-quality water or leaching fractions >0.4, would probably lead to greater differences in root-zone EC between standard leached and minimum-leached pots than were seen in these studies.

There was a relationship between irrigation method, EC in the growing media, and growth of the plants. Our experience in growing New Guinea impatiens under conventional, overhead irrigation with leaching is that optimum EC for established plants is in the range of 1.5 to 2.5 dS·m⁻¹ using standard SME methods (Warncke, 1986). For the 12 mmol·L⁻¹ N treatment, EC levels in the root zone remained generally constant between 1.5 to 2.0 dS·m⁻¹ during the cropping period (Figs. 2C and 3C). At 18 mmol·L⁻¹ N, root-zone EC began to increase after ≈6 weeks in both irrigation treatments, coincident with differential dry-mass accumulation of the plants (data not shown). At the end of the cropping period, root-zone EC levels ranged from 3.0 to 4.0 dS·m⁻¹ in Expt. 1 (Fig. 2E) and 2.4 to 3.0 dS·m⁻¹ in Expt. 2 (Fig. 3E). As mentioned earlier, there were no signs of salt toxicity, such as leaf necrosis or spotting, on plants grown under 18 mmol·L⁻¹ N treatments. However, with the relatively high EC readings, the growing medium osmotic potential may have increased enough to suppress maximum water uptake during the later stages of production (Haver and Schuch, 1996). The consequences of a high root-zone EC were probably more severe in plants in the 18 mmol·L⁻¹ N treatments that were not leached. Root-zone EC levels in the 6 mmol·L⁻¹ N treatments re-

Fig. 2. Electrical conductivity and pH in growing media over a 10-week cropping period under different fertilizer rates and drip irrigation treatments in Expt. 1. (A and B) N at 6 mmol·L⁻¹, (C and D) N at 12 mmol·L⁻¹, and (E and F) N at 18 mmol·L⁻¹. Closed symbols (■, ●) indicate minimum-leach irrigation, while open symbols (□, ○) indicate leach treatments. Readings were taken from media collected from the upper one-third layer (●, ○) or bottom two-thirds layer (■, □) of the pot. Each point represents the mean of six observations. Error bars indicate ±SE.

mained relatively low throughout production, and probably could not supply nutrients to adequately support the growth of the plants. However, why plants in this treatment grew less under minimum-leach irrigation is not clear (Table 1). EC levels in the root zone were similar in both irrigation treatments (Figs. 2A and 3A), and poor growth in the minimum-leach treatments might have been a result of moderate water stress rather than inadequate nutrient levels.

Growing medium pH levels were relatively consistent among treatment combinations for both layers of medium in Expt. 1 (Fig. 2B, D, and F). Readings in the top one-third layer were ≈0.5 to 1.0 units lower than in the bottom layer. Root-zone pH rose rather quickly beginning at planting, but then tended to level off over the last half of the production period. Since RO water was used in all fertilizer solutions, pH did not rise due to high water alkalinity. After 10 weeks of cropping, pH in the root zone ranged from 5.3 to 5.7. Irrigation method, but not fertilizer concentration, significantly

affected pH level in the root zone, as standard leached treatments had slightly higher readings than did minimum-leached treatments. This agrees with results using poinsettia (Yelanich and Biernbaum, 1993) and geranium (Ku and Hershey, 1992), where increased leaching over an 8- to 10-week period increased root-zone pH.

The pH of the medium was generally higher in Expt. 2 (Fig. 3B, D, and F) than in Expt. 1 (Fig. 2B, D, and F); more dolomitic limestone was added to preplant media in the second experiment (8 kg·m⁻³ in Expt. 2 vs. 6 kg·m⁻³ in Expt. 1) to raise beginning pH readings to ≈6.0. As in Expt. 1, pH readings in the upper layer were lower than in the root zone. In contrast to the first experiment, there was not a significant effect of irrigation treatment. After an initial rise during the first 3 weeks, pH in both layers gradually began to decrease. After 9 weeks, pH in both layers of the medium differed significantly among fertilizer treatments. Higher fertilizer concentrations reduced pH, as has been shown in several

Fig. 3. Electrical conductivity and pH in growing media over a 9-week cropping period under different fertilizer rates and drip irrigation treatments in Expt. 2. (A and B) N at 6 mmol·L⁻¹, (C and D) N at 12 mmol·L⁻¹, and (E and F) N at 18 mmol·L⁻¹. Closed symbols (■, ●) indicate minimum-leach irrigation, while open symbols (□, ○) indicate leach treatments. Readings were taken from media collected from the upper one-third layer (●, ○) or bottom two-thirds layer (■, □) of the pot. Each point represents the mean of nine observations. Error bars indicate $\pm$ SE.

recent studies (Argo and Biernbaum, 1997; Dole et al., 1994). This effect is generally thought to be related to the ratio of $\text{NH}_4^+\text{-N}$: $\text{NO}_3^-\text{-N}$ in the fertilizer and the total amount of N supplied (Marschner, 1995). Why pH levels in Expt. 1 did not decrease in response to fertilizer concentration as in Expt. 2 is not clear. At the end of production, root-zone pH levels in Expt. 2 ranged from 5.6 to 6.4 and were still in an acceptable range. Although pH of the growing medium varied between treatments in both experiments, it probably did not affect plant growth as did EC.

Solution use. As would be expected, the minimum-leach treatments used less solution because application stopped when the tension in the medium reached -0.1 kPa (data not shown). At 12 mmol·L⁻¹ N (fertilizer concentration producing the largest plants), plants in the standard leach treatments required $\approx 30\%$ more solution than did those with minimum leaching. The differences in solution use were slightly greater at the other fertilizer rates. While drip irrigation significantly reduces

solution use in comparison with hand watering or capillary mat irrigation (Dole et al., 1994), it can still be very inefficient unless leaching is carefully controlled (Holcomb et al., 1992). From a grower's point of view, the savings in fertilizer and water use in a minimum-leach system may be worth the trade-off in the time needed to manage closely the growing medium for optimum salt level. Other factors, such as avoiding the large capital investment costs of ebb and flow and other recirculating irrigation systems, also favor minimum-leach drip irrigation.

Total N runoff from the standard leached treatments was closely tied to fertilizer solution use. Combined N runoff from both experiments for the 6, 12, and 18 mmol·L⁻¹ N treatments was 8.5, 19.8, and 29.2 g·m⁻² bench space, respectively. Most (75% to 85%) of the runoff N was as NO_3^- , with the remainder as NH_4^+ . We assume that some of the $\text{NH}_4^+\text{-N}$ from the fertilizer was retained in the growing media, since freshly prepared nutrient solutions used in both experiments contained $\approx 45\%$

$\text{NH}_4^+\text{-N}$ and 55% $\text{NO}_3^-\text{-N}$. Nitrification in the medium and plant uptake of $\text{NH}_4^+\text{-N}$ also probably contributed to the large amount of $\text{NO}_3^-\text{-N}$ in the runoff. Nitrites were not detected in runoff samples from either experiment. Treatments using minimum-leach irrigation produced insignificant amounts of solution runoff (estimated at <2 mL per container) and solution samples were not analyzed.

In summary, New Guinea impatiens can be grown under minimum-leach drip irrigation with water-soluble fertilizers if rates are carefully selected and water quality is acceptable. Periodic monitoring of the root-zone medium EC throughout the production period is essential for maximizing plant growth and quality. Irrigation with poorer quality water than used in this study would probably require closer monitoring of the growing medium. Computer-controlled irrigation using microtensiometers is a convenient and successful way to deliver water-soluble fertilizers and provide uniform moisture in a minimum-leach system when drippers are calibrated and moisture is applied slowly and consistently. Although not tested in this study, moisture setpoints can probably be altered, or tap water used when medium EC is greater than a predetermined acceptable maximum value. Further studies are needed to determine the effect of different potting media in such a system and how they might influence leaching fractions needed to reduce high medium EC levels.

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