New Guinea Impatiens Growth Response and Nutrient Release from Controlled-release Fertilizer in a Recirculating Subirrigation and Top-watering System

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Abstract. New Guinea impatiens (*Impatiens hawkeri* Bull.) 'Illusion' were grown in a recirculating subirrigation system under various rates and placements of 14N–6.1P–11.6K (Osmocote; Scotts-Sierra, Marysville, Ohio) resin-coated, controlled-release fertilizer (CRF). Four CRF placements (incorporated, top-dressed, bottom, and dibble) were tested. Incorporated placement yielded slightly greater dry weights than the other placements. A rate experiment tested incorporating from 0.5 to 2 times the fertilizer manufacturer's recommended rate of 7.11 kg·m⁻³. All shoot growth parameters (height, leaf number, shoot, and root fresh and dry weight) exhibited a significant quadratic response, as exemplified by shoot dry weight, where shoot dry weight increased up to the 1.5× rate, after which shoot dry weight decreased. A quadratic response surface model revealed that the optimum rate response ranged from 1.16× rate for height to 1.47× rate for shoot dry weight. The lower bound of the 95% confidence interval (CI) would be the lowest rate at which one could expect maximum growth response. The lower bound of the 95% CI varied from 0.56× rate for height to 1.30× rate for shoot dry weight. Thus, the lowest rate that would be within the 95% CI for all growth parameters, and thus yield maximum growth response, would be the 1.30× rate. Electrical conductivity (EC) of the growing media increased significantly with increasing CRF rate. At all rates, EC was significantly greater in the top layer than in the middle and bottom layers. Only in the 1.75× and 2× rates did EC exceed the recommended EC levels in the middle and bottom layer. All rates >0.75× exceeded recommended EC in the top layer. Release characteristics and total nutrient balance of the CRF was compared in subirrigated and top-watered systems. There was no significant difference between top-watered and subirrigated treatments for the amount of K recovered in plant tops and released from prills. By day 84, in subirrigation, 46% of the K was still in the prills, 41% was recovered in the plant tops, and 22% was recovered in the medium. Similar results were obtained in the top-watering treatment, except that a lesser amount was recovered in the medium (9%) and a small amount (4%) was recovered in the leachate. The uptake of K by plants and release of K by the CRF were inversely proportional and linear with respect to time. Of the K released from the prills, 77% and 83% were recovered in the plant tops for subirrigation and top-watering, respectively, indicating very high fertilizer use efficiency.

The high value of greenhouse and nursery crops dictates intensive production methods. Frequent irrigation and fertilization, as well as the use of chemical growth retardants and pesticides, are common practices in the greenhouse/nursery industry. These production

practices have led to ground and surface water contamination, and regulations to control environmental pollution by the greenhouse/nursery industry are increasing (Molitor, 1990; Reed, 1996). In the interest of curbing pollution of our natural resources, fertilization practices may need to be modified (Birnbaum, 1992).

The use of controlled-release fertilizers (CRF) may reduce the amount of fertilizer runoff from greenhouse crops, especially when combined with zero-leach irrigation systems (Reed, 1996). The most common zero-leach system is recirculating subirrigation, which completely eliminates leaching and runoff, and is becoming increasingly popular with greenhouse growers, especially in Europe (Molitor, 1990). Both CRF and recirculating subirrigation can increase fertilizer efficiency and decrease fertilizer runoff in greenhouse crops (Birnbaum, 1992), but few studies have been conducted that combine both methods (Morvant et al., 2001).

The objectives were to determine the optimum rate and placement of CRF for growing New Guinea impatiens in a recirculating subirrigation system, and characterize the release rates of CRF and nutrient balance in subirrigation vs. top-watering.

Materials and Methods

Rate × placement experiment. New Guinea impatiens 'Illusion' (*Impatiens hawkeri* Bull.) rooted cuttings (Oglevee Ltd., Connellsville, Pa.) were transplanted into 11-cm-wide × 9.5-cm-tall (460-mL) plastic containers on 9 Oct. 1997. Soilless growing medium used was a peat-perlite based mix, adjusted for pH (≈5.6) and with no preplant nutrient charge (Sunshine no. 2; Sun Gro Horticulture, Terrell, Texas), and amended with 0.5 kg·m⁻³ Micromax trace element mix (Grace-Sierra, Milpitas, Calif.). Newly transplanted plants were top-watered once with reverse osmosis-purified water (RO) to settle the medium. After drainage, pots were placed into subirrigation trays. Subirrigation started on 13 Oct. and was terminated on 11 Dec. 1997 (day 63). The experiment was conducted in a glasshouse with an average daily noontime temperature and light intensity of 23.3 ± 2.1 °C and 462 ± 388 μmol·m⁻²·s⁻¹ photosynthetic photon flux (PPF) (Quantum Light Logger model 3600; Spectrum Technologies, Plainfield, Ill.), respectively.

Experimental design was an incomplete factorial of four CRF rates of 0.25, 0.5, 0.75, and 1.0 times the recommended label rate (1.78, 3.56, 5.33, and 7.11 kg·m⁻³, respectively) times two CRF placements (incorporated and top-dressed), plus 0.5 times the label rate with two additional placements (dibble and bottom); with 10 plants harvested per treatment. Osmocote 14N–6.1P–11.6K, 3 to 4 month release, resin-coated CRF (Scotts-Sierra, Marysville, Ohio) was either incorporated throughout the medium, applied as a top-dress, dibble applied into the bottom of the planting hole, or layered 1 cm from the bottom of container. Plants were placed in subirrigation trays (100 × 110-cm subirrigation trays, Midwest Growmaster, St. Charles, Ill.). Tensiometers (model MLT; Irrrometer Co., Riverside, Calif.) were placed in an extra pot with plant (not considered for experimental results) in each tray, and plants were watered when the medium moisture tension exceeded 7 kPa. At each irrigation, trays were flooded to a depth of 2 cm with RO purified water. Trays required 2 to 3 min to fill, 2 to 3 min to drain, and were held flooded for 10 min, or until the tensiometer reading returned to 0 kPa and the surface of the medium was rewetted.

Plant height (soil surface to top of tallest leaf), leaf number, and flower number (opened flowers) were measured weekly until final harvest (day 63). At final harvest, plant tops were cut off at the medium surface, and leaf area (model AM82 leaf area meter; Delta-T Devices Ltd., Cambridge, U.K.) and fresh weight were measured. Plant tops were dried at 40 °C for 48 h, and then weighed for dry weight. The growing medium of each pot was cut into three equal-sized horizontal lay-

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ers (top, middle, and bottom), air-dried, and subsamples were removed from each layer to determine electrical conductivity (EC) and pH by the 1:2 dilution method (Warncke and Krauskopf, 1983). Prills were not removed since preliminary studies demonstrated no significant effect of prill removal on EC or pH (data not shown). EC was measured using a conductivity/TDS meter (model 44600; Hach, Co., Loveland, Colo.) and pH was measured using a model 701 A pH meter (Orion Research, Cambridge, Mass.).

Rate experiment. This experiment was to better define the effect of rate using incorporated placement. Rooted cuttings of *Impatiens hawkeri* 'Illusion' were transplanted as in the rate $\times$ placement experiment. The experimental design was a single factorial design of CRF rates of 0.5, 0.75, 1.0, 1.25, 1.5, 1.75, and 2.0 times the recommended label rate (3.56, 5.33, 7.11, 8.89, 10.67, 12.44, and 14.22 kg·m⁻³, respectively), with 10 plants harvested per treatment. The experiment started on 8 Apr. and was terminated on 9 June 1998 (day 63). In addition to those parameters measured in the rate $\times$ placement experiment, root fresh and dry weights were determined. Average daily noontime greenhouse temperature and light intensity were 23.2 $\pm$ 2.3 °C (HOBO sensor; Spectrum Technologies) and 840 $\pm$ 363 μ mol·m⁻²·s⁻¹ PPF, respectively. All other methods and procedures were as in the rate $\times$ placement experiment.

Release rate experiment. This experiment was designed to determine the total nutrient balance and release characteristics of Osmocote 14N-6.1P-11.6K CRF when used in recirculating subirrigation vs. top-watering. The experiment started on 15 Sept. 1998 and was terminated on 8 Dec. 1998 (day 84). Rooted cuttings of *Impatiens hawkeri* 'Illusion' were transplanted as in previous experiments. The recommended CRF label rate of 7.11 kg·m⁻³ (4.47 g per 460 mL pot) was used and plants were either subirrigated or top-watered. CRF prills were incorporated into the media, and were counted prior to incorporation and upon removal from media (to ensure all were recovered for analysis).

The experiment was conducted in a growth chamber with temperature set points of 21 °C days/18 °C nights, a photoperiod of 16 h (0600 to 2200 HR), and a light intensity of 650 μ mol·m⁻²·s⁻¹ PPF.

Fifty subirrigated plants were placed in subirrigation trays, each containing 25 plants, while 50 top-watered plants were placed on an adjacent wire bench. As in previous experiments, tensiometers were used to monitor growing medium moisture tension and determine irrigation timing. When top-watering, a leaching fraction (fraction of water applied that was collected as leachate) of 0.4 was collected in a cup placed beneath each pot. After each watering, leachate volume was measured and 1-mL samples were frozen at -5 °C for later analysis. Since the leachate volumes were consistent between waterings, samples from each watering were pooled to avoid excessive analysis.

Five randomly selected plants were har-

vested biweekly from each treatment until experiment termination. At each harvest, total nutrient balance of K was determined for plant tops, media + roots, recirculated irrigation water, leachate, and incorporated fertilizer prills at each harvest. Plant tops were cut off at the surface of the medium, dried and ground to pass through a 20-mesh screen in a Wiley mill, and stored for later digestion via nitric acid plant tissue digest (Havlin and Soltanpour, 1980) for K analysis. Media (with roots) were divided into thirds as in previous experiments. The CRF prills were removed by hand from each layer and stored in 20-mL plastic vials at room temperature (24 °C) for later analysis. For analysis of prills, 15 mL of 0.1 N HCl was added to the vials and prills were allowed to sit overnight. Prills were then sonicated (model 60, Sonic Dismembrator; Fisher Scientific Co., Pittsburgh) until completely broken up. The resulting slurry was brought to 1 L volume with nanopure water, stirred, filtered, and analyzed for K. The growing medium was air-dried, after removal of the prills, sieved through a #8 sieve, and then extracted by the Mehlich III acid extraction procedure (Tran and Simard, 1993) for K analysis.

All samples were assayed for K content by Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES) (Dahlquist and Knoll, 1978). Potassium was chosen as a marker for release rate and distribution because K does not form complexes (unlike P), K exists in only one form (unlike N, which can be present as ammoniacal and/or nitrate N), and K is not subject to volatilization (unlike several N forms).

Amount of K in each sample was determined for plant tops, media + roots, prills, leachates (for top-watered pots), and recirculated irrigation solution (for subirrigated pots). The initial K in plants and medium at zero time was subtracted from timed harvest measurements. In addition, five 4.47-g samples of unused prills were analyzed to determine the initial amount of K added to each pot. Analysis revealed 0.57680 g K per 4.47 g prills (12.9% K) added per pot, which exceeds the manufacturer's label analysis of 0.51852 g K per 4.47 g prills (based on 11.6% K analysis). For calculating nutrient balance, the analytically measured 0.57680 g K added per pot was used.

Statistical analysis was analysis of variance by SAS. The optimum rates were determined with a quadratic response surface model (SAS RSREG), and the lower and upper 95% CIs were determined with PROC GLM.

Results and Discussion

Rate $\times$ placement experiment. In subirrigation, water movement is primarily upward; hence this study was conducted to determine the effectiveness of top-dressed vs. other methods that incorporated the CRF into the medium. There was a significant effect of rate on all growth parameters measured, except leaf chlorophyll (Table 1). As rate increased, growth parameters increased. There was a significant effect of fertilizer placement on all growth

parameters, except height (Table 1). When comparing plants grown at the 0.5 $\times$ rate with the four different CRF placements, incorporated placement produced slightly greater shoot fresh and dry weight, leaf number and leaf area than the other three placements (Table 1). Using surface applied irrigation, similar placement results were found by Johnson and Warden (1975) using *Celosia argentea* L. Ann., and by Rauch (1989) using areca palm seedlings. In addition, Oertli and Lunt (1962) found that top-dressed CRF released nutrients much more slowly than incorporated CRF.

When CRF was incorporated throughout the growing medium, EC of all layers increased with increasing fertilizer rate (Table 2). When CRF was top-dressed, EC did not increase with increasing fertilizer rate in the middle and bottom layers. EC of the layers with the dibble placement was similar to top-dress placement. EC of the layers with the bottom placement was highest in the top and bottom layers. Growing medium EC was highest in the top one-third of the pot, regardless of placement. These results are similar to those found in previous studies showing increasing EC with increasing CRF rate and increased EC in the top layer as compared to the middle and bottom layers (Argo and Biernbaum, 1995).

The differences in plant growth between placements at the 0.5 $\times$ rate (Table 1) were not as large as differences in EC between the placements and layers (Table 2). This may be because EC did not exceed the upper recommended level of either 1.2 dS·m⁻¹ (Lang, 1996) or 1.5 dS·m⁻¹ (Warncke and Krauskopf, 1983) in any layer with any placement, except the top-dressed treatment at the 1 $\times$ rate.

Rate experiment. Plants exhibited increasing size with increasing fertilizer rate up to the 1.5 $\times$ rate, above which size decreased (Fig. 1). Plants grown at the 0.5 $\times$ rate had smaller leaves with more purple coloration and were generally less robust than plants in other treatments. No specific symptoms (necrosis, marginal cupping, etc.) of salt injury were noticed, even at the highest fertilization rates.

All growth parameters measured showed significant differences with increasing fertilizer rate (Table 3). Root growth (fresh and dry weight) decreased dramatically at the higher rates. All shoot growth parameters exhibited a significant quadratic response (Table 3), as exemplified by shoot dry weight, where shoot dry weight increased up to the 1.5 $\times$ rate, after which shoot dry weight decreased (Fig. 2). The quadratic response surface model revealed that the optimum rate response ranged from 1.16 $\times$ rate for height to 1.47 $\times$ rate for shoot dry weight (Table 3). The lower bound of the 95% CI would be the lowest rate at which one could expect maximum growth response. The lower bound of the 95% CI varied from 0.56 $\times$ rate for height to 1.30 $\times$ rate for shoot dry weight. Thus, the lowest rate that would be within the 95% CI for all growth parameters, and thus yield maximum growth response, would be the 1.30 $\times$ rate. These results are similar to other studies in both top-water and subirrigation systems, which have shown that with many species CRF must be used at higher than recom-

Table 1. The effect of rate and placement of CRF on growth response of New Guinea impatiens 'Illusion' grown in a recirculating subirrigation system (final harvest).

Placement ^y	Rate	Growth parameter ^z						
		Height (cm)	Shoot fresh st (g)	Shoot dry wt (g)	Leaf area (cm ²)	Chlorophyll units (spadmeter)	Leaf no.	Flower no.
Incorporated	0.25x ^x	12.0	38.5	2.95	284	40.1	30.3	5.3
	0.5x	15.8	78.2	6.13	646	46.2	65.8	9.0
	0.75x	17.1	86.9	6.35	931	46.3	73.7	12.8
	1x	19.2	111.6	7.92	1149	50.1	92.1	14.3
Top-dressed	0.25x	10.7	31.3	2.61	291	43.9	30.2	3.6
	0.5x	16.6	66.3	4.99	586	46.3	59.3	7.2
	0.75x	16.9	77.2	5.85	693	50.4	68.1	7.2
	1x	17.2	91.2	6.86	1018	50.8	81.3	6.9
Bottom	0.5x	15.9	65.4	4.88	565	46.4	59.6	4.6
Dibble	0.5x	15.9	72.1	5.16	455	46.2	56.0	16.9
<i>Significance</i>								
Placement		NS	***	***	***	***	**	***
Rate		***	***	***	***	NS	***	***
Placement × rate		*	NS	NS	**	**	NS	*

^zData represents means of ten replications.^yIncorporated = incorporated into the medium; Top-dressed = top-dressed on the surface of the medium; Bottom = placed in the bottom 1 cm of medium; Dibble = applied into the transplant hole.^xx = manufacturer's recommended rate of 7.1 kg·m⁻³.NS, *, **, *** Nonsignificant or significant at $P < 0.05$, 0.01, or 0.001, respectively.

Table 2. EC of the top, middle, and bottom layers of growing medium from New Guinea impatiens 'Illusion' grown at varying rates and placements of CRF in a recirculating subirrigation system (final harvest).

Placement ^y	Rate	EC (dS·m ⁻¹) ^z		
		Top	Middle	Bottom
Incorporated	0.25x ^x	0.43	0.22	0.18
	0.5x	0.73	0.43	0.22
	0.75x	0.68	0.53	0.35
	1x	1.24	0.70	0.55
Top-dressed	0.25x	0.30	0.06	0.06
	0.5x	0.25	0.06	0.06
	0.75x	0.36	0.07	0.06
	1x	0.41	0.07	0.06
Bottom	0.5x	0.26	0.08	0.23
Dibble	0.5x	0.30	0.11	0.06
<i>Significance</i>				
Placement			***	
Rate			***	
Layer			***	
Placement × rate			***	
Placement × layer			***	
Rate × layer			**	
Placement × rate × layer			NS	

^zData represents means of 10 replications.^yIncorporated = incorporated into the medium; Top-dressed = top-dressed on the surface of the medium; Bottom = placed in the bottom 1 cm of medium; Dibble = applied into the transplant hole.^xx = manufacturer's recommended rate of 7.1 kg·m⁻³.NS, **, *** Nonsignificant or significant at $P < 0.01$ or 0.001, respectively.

mended label rates to achieve optimum growth (Kovacic and Holcomb, 1981; Lamont et al., 1990; Rauch, 1989), including New Guinea impatiens (Rauch and Murakami, 1994). However, Haver and Schuch (1996) found, in a no-leach system at high moisture content, that the biomass of New Guinea impatiens 'Illusion' was greatest at the recommended CRF label rate and biomass decreased at the 1.5x rate. This may have been caused by high EC levels reported in all layers of the container in the no leach system used.

EC of the growing medium increased with increasing fertilizer rate (Fig. 3). At all rates, EC was significantly higher in the top layer than in the middle and bottom layers. For a 1:2

dilution extraction, 1.2 dS·m⁻¹ (Lang, 1996) to 1.5 dS·m⁻¹ (Warncke and Krauskopf, 1983) are commonly recommended upper limits for EC. At 1x and higher rates, the EC of the top layer exceeded these recommended EC levels. High EC in the top layer is not always damaging, probably due to fewer roots in the top layer (Kent and Reed, 1996). Only at the 1.75 and 2x rate did the EC of the middle layer exceed these recommended EC levels, while the EC of the bottom layer never exceeded the recommended EC at any rate. Growth reduction (Fig. 2) only occurred when the recommended EC was exceeded in both the top and middle layers (Fig. 3).

Growing medium pH decreased in all layers

as rate increased, with the greatest decrease in the top layer (Fig. 3). The pH decrease can be attributed to nitrification due to the higher level of ammoniacal N than nitrate N in Osmocote. When CRF rates are increased, more ammonium is available for nitrification, thus causing the pH to decrease. These results are similar to those found by Jarrell et al. (1983) and Lamont et al. (1987). These trends in pH were inversely proportional to the trends of EC, and were probably caused by accumulation of ammoniacal N as a component of the measured EC.

Release rate experiment. The total K recovered by the plant/medium/leachate system averaged 105.4% ± 9.8% (Table 4). This level of

Fig. 1. New Guinea impatiens 'Illusion' grown at rates of 0.5, 0.75, 1, 1.25, 1.5, 1.75, and 2 times the recommended rate of CRF in a recirculating subirrigation system (day 63, final harvest).

Table 3. The effect of rate of CRF on growth response of New Guinea impatiens 'Illusion' grown in a recirculating subirrigation system (final harvest).

Rate	Height (cm)	Leaf no.	Flower no.	Shoot		Root	
				Fresh wt (g)	Dry wt (g)	Fresh wt (g)	Dry wt (g)
0.5x ^y	15.7	50.4	25.2	60.78	4.73	13.80	0.99
0.75x	16.7	70.8	41.8	84.62	6.39	---	---
1x	16.8	86.6	48.3	108.70	8.23	13.67	1.04
1.25x	16.3	87.4	50.2	110.10	8.12	---	---
1.5x	17.1	98.8	53.6	128.08	9.42	---	---
1.75x	16.5	88.8	49.0	123.82	8.99	---	---
2x	14.5	72.3	36.2	94.43	7.39	6.72	0.54
<i>Significance</i>							
Rate	***	***	***	***	***	***	***
Quadratic	****	****	****	****	****	---	---
R ²	0.75	0.96	0.97	0.93	0.94	---	---
Optimum rate ^w	1.16	1.40	1.35	1.45	1.47	---	---
Lower 95% CI ^v	0.56	1.25	1.22	1.28	1.30	---	---
Upper 95% CI ^w	1.76	1.54	1.47	1.62	1.63	---	---

^yData represent means of 10 replications.

^yx = manufacturer's recommended rate of 7.1 kg·m⁻³.

^yDash indicates data not collected, or insufficient data to calculate.

^wDetermined by quadratic response surface model SAS RSREG.

^vCI = confidence interval; determined by PROC GLM.

, *Significant at $P < 0.001$ or 0.0001, respectively.

Fig. 2. Shoot dry weight of New Guinea impatiens 'Illusion' grown at rates of 0.5, 0.75, 1, 1.25, 1.5, 1.75, and 2 times the manufacturer's recommended rate of CRF in a recirculating subirrigation system (final harvest). Dry weight can be expressed by $y = -4.730x^2 + 13.877x - 1.164$, $R^2 = 0.94$, with an optimum rate response of 1.47x rate, and a 95% CI of 1.30x to 1.63x rate.

variability is acceptable given the complexities of the experimental recovery of K.

There were no significant differences between top-watered and subirrigated treatments for the amount of K recovered from plant tops and prills. For both subirrigation and top watering, K content in plant tops significantly (Table 4) and linearly (Fig. 4) increased with time. At final harvest (day 84), ~45% of the K from the CRF was recovered in the plant tops. Potassium content remaining in the CRF prills significantly decreased with time, and was inversely proportional to K recovered in the plant tops. At final harvest, ~55% of the K had been released from the prill. Similarly, Holcomb (1981), studying K release rates from several CRFs, found there were no significant differences between subirrigation vs. top-watering in recovery of K in the plant tops or K release from the prill.

The amount of K recovered from the growing medium was significantly affected by irrigation method. In subirrigation, the greatest %K tended to be recovered in either the top or middle layer of the growing medium, and in top-watering the %K recovered is more evenly distributed between the layers (Table 4). Fertilizer and irrigation water salts have been shown by previous research to accumulate in the top layer of growing media of subirrigated plants (Argo and Biernbaum, 1995; Haver and Schuch, 1996; Kent and Reed, 1996; Molitor, 1990). At final harvest, the growing medium had accumulated more K in subirrigation (sum of all layers equals 23% of the applied K) than in top-watering (sum equals 9%). This is partially caused by leaching of K in the top-watering treatment and partially caused by the greater accumulation of K in the top layer of the subirrigation treatment.

In top-watered treatments, relatively small amounts of the total K were recovered in the leachates (0.4 leaching fraction). On day 14, ~8% of the K was recovered from leachates, however, by day 84, only 4% of the K was recovered from leachates. This indicates that when the plants are newly transplanted and their root systems are not fully developed, they are less efficient at taking up available nutrients compared to later in their life cycles. Thus, early in the crop, the released K accumulates in the medium and is available for increased leaching. This has been reported for many plants, including New Guinea impatiens (Hartley, 1995). In fact, it is commonly recommended that New Guinea impatiens rooted cuttings or seedlings not be fertilized at all during the first two to three weeks after transplanting (Erwin et al., 1992; Hartley, 1995).

Irrigation solution that had been recirculated in the subirrigated treatments over the course of the experiment was also tested for K content, but no K was detected. This would indicate that, as has been reported previously (Reed, 1996), irrigation solution taken up by the growing medium remains there, with no appreciable loss back to the subirrigation tanks. If the container is not flooded too deeply (2 cm in these experiments), the water that enters the container probably remains as a perched water table upon draining. In other words,

Fig. 3. EC and pH of the top, middle, and bottom layers of growing medium from New Guinea impatiens 'Illusion' grown at rates of 0.5, 0.75, 1.0, 1.25, 1.5, 1.75, and 2 times the manufacturer's recommended rate CRF in a recirculating subirrigation system (final harvest). Bars represent standard error of the mean. Dashed line represents the recommended maximum EC level of $1.5 \text{ dS} \cdot \text{m}^{-1}$.

Table 4. Percent potassium from CRF recovered in plant tops, media + roots, prills, and leachate recovered over time for New Guinea impatiens 'Illusion' grown in a recirculating subirrigation and top-watered irrigation system (final harvest).

	% Potassium ^z						
		Media (+ roots) ^y				Recirculating solution ^x or	
Day	Plant tops	Top	Middle	Bottom	Prills	leachate	Total
Recirculating subirrigation							
0	---	---	---	---	100	nd ^x	100 ± 4.93 ^y
14	2.8	5.99	3.17	2.23	77.1	nd	91 ± 3.92
28	8.2	11.74	5.42	2.35	77.9	nd	106 ± 4.06
42	14.9	7.55	1.98	4.52	68.4	nd	100 ± 2.80
56	23.6	4.51	5.27	2.69	62.6	nd	99 ± 6.78
70	35.0	5.86	6.02	2.84	51.3	nd	101 ± 3.67
84	41.4	5.88	9.61	7.03	45.9	nd	110 ± 9.40
Top-watered							
0	---	---	---	---	100	---	100 ± 4.93 ^y
14	3.5	4.81	7.91	6.32	92.2	8.20 ^w	123 ± 9.66
28	8.2	2.04	5.77	2.62	79.8	2.23	101 ± 4.65
42	18.2	4.93	4.91	3.84	68.6	3.97	104 ± 4.18
56	24.3	3.25	3.17	2.64	61.2	3.43	98 ± 4.12
70	31.0	2.52	3.84	4.85	54.4	4.39	101 ± 4.16
84	45.8	1.41	4.45	3.07	45.1	3.84	104 ± 5.96
Significance							
Irrigation method (IM)	NS	***			NS		
Day	***	*			***	***	
IM × day	NS	***					
Layer		***			NS		
IM × layer		***					
Day × layer		*					
IM × day × layer		***					

²Data represent means of five replications.

³Media divided into top, middle, and bottom thirds, with respect to height of the container.

^x%K recovered in recirculating solution; nd = not detectable.

^w%K recovered in leachate at 0.4 leaching fraction.

^yAverage total %K ± standard deviation of the mean; 100% equals $577 \pm 28.5 \text{ g K}$ added per container.

NS, *, *** Nonsignificant or significant at $P < 0.05$ or 0.001, respectively.

Fig. 4. Percent K remaining in prills and recovered from plant tops of New Guinea impatiens 'Illusion' grown with the label recommended rate CRF in a recirculating subirrigation system. Percent K remaining in prills can be expressed by $y = 0.880x - 0.005$, with $R^2 = 0.745$ ($P = 0.0001$); percent K recovered from plant tops can be expressed by $y = 0.006x - 0.073$, with $R^2 = 0.921$ ($P = 0.0001$). Bars represent standard error of the mean.

Fig. 5. Complete K balance for New Guinea impatiens 'Illusion' grown with the label recommended rate of CRF in recirculating subirrigated and top-watered systems (final harvest). Bars represent standard error of the mean.

there is virtually no downward leaching in subirrigation, even from the lower flooded portion of the container. However, one could consider accumulation of salts in the top layer (Fig. 4, Table 4) upward leaching out of the root zone.

For total K balance at final harvest, both K recovered in plant tops and K released from the prills were not significantly different between irrigation methods (Table 4, Fig. 5). About 45% of the original K was still in the prills at final harvest. This is equivalent to slightly greater

than half of the K being released after about three-fourths of the manufacturer's stated useful product life (≈ 112 days at 21°C).

Calculations of fertilizer use efficiency (proportion of K recovered in plant tops to K released from the CRF) for this experiment were 77% and 83% for subirrigation and top-watering, respectively. However, this is an underestimate since K in roots was not measured. These results indicate that CRFs have a very high fertilizer use efficiency and are similar to those reported by Holcomb

(1980), who found the fertilizer use efficiency of Osmocote CRF to be 89% and that of a comparable water-soluble fertilizer to be only 46% (irrigation method not listed). Similarly, Morvant et al. (2001) found a combination of CRF and subirrigation yielded 90% fertilizer use efficiency.

In summary, with respect to placement, New Guinea impatiens grown with CRF incorporated were slightly larger than were those grown with CRF top-dressed, dibbled, or placed in the bottom of the pot (Table 1). For New Guinea impatiens grown in recirculating subirrigation, the optimum rate was determined to be the $1.3\times$ rate (Table 3, Fig. 2). These results are consistent with those found by other researchers who found recommended CRF rates were too low for many plant species (Kovacic and Holcomb, 1981; Lamont et al., 1990; Rauch, 1989), including New Guinea impatiens (Rauch and Murakami, 1994). This is contrary to soluble fertilizer added in subirrigation where lower than normally recommended rates for top-watering were found to be optimum (Kent and Reed, 1996; Reed, 1996). Both K recovered in plant tops and released from prills were approximately linear with respect to time, regardless of irrigation method. In recirculating subirrigation systems, a significant amount of K is accumulated in the upper layer of the growing media. The salts move up in the container profile with water and are left behind upon evaporation from the soil surface. This amounts to what could be called "upward leaching." In top-watered systems, very little K is lost as a result of leaching after the first two weeks. This is probably associated with root development and root absorption of the released K, and the maintenance of low leaching fractions. This indicates that CRFs may successfully be used to reduce runoff of K, even when plants are top-watered, if reasonably leached. An additional benefit of using CRFs is an extremely high fertilizer use efficiency.

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