Growth Response, Nutrient Leaching, and Mass Balance for Potted Poinsettia. I. Nitrogen

Catherine S.M. Ku¹ and David R. Hershey²

Department of Horticulture and Landscape Architecture, University of Maryland, College Park, MD 20742-5611

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Abstract. Single-pinned poinsettias (*Euphorbia pulcherrima* Willd. ex Klotzsch 'V-14 Glory') received 210 mg·L⁻¹ constant N fertigation from Hoagland solution with N sources of 100% NO₃-N or 60% NO₃-N : 40% NH₄-N, P concentrations of 7.8 or 23 mg·L⁻¹, and leaching fractions (LFs) of 0, 0.2, or 0.4. The P fertigation rates did not significantly affect plant growth measurements and N leaching. Shoot dry masses and leaf and bract areas of plants fertigated with 60% NO₃-N were 11% to 26% greater than those fertigated with 100% NO₃-N. Shoot dry mass at the 0 LF was 27% smaller than those at the 0.4 LF. The total amount of N applied via fertigation was 1.7 g at the 0 LF and 3.3 g at the 0.4 LF. Leachate N concentration ranged from 170 to 850 mg·L⁻¹. Nitrogen recovery was 74% to 91%, and the percentage of fertigation N recovered in leachate ranged from 51% at the 0.2 LF to 74% at the 0.4 LF. With a 0.4 LF and 210 mg·L⁻¹ N fertigation, 15% to 22% of the recovered N was found in the shoots, and 68% to 75% was found in the leachate. Even with a 0.2 LF, >50% of the N recovered was found in the leachate. Premium marketable quality poinsettia were produced with N at 210 mg·L⁻¹ from 60% NO₃-N : 40% NH₄-N fertigation solution at the 0.4 LF. To reduce N leaching to the environment, good marketable quality poinsettias could be grown at a LF of ≤0.2 with 210 mg·L⁻¹ N fertigation if quality irrigation water is available and if a small reduction in growth is acceptable.

A marketable poinsettia should be compact with dark green leaves and large attractive bracts. Because underfertilization can reduce plant quality, recommendations for poinsettia production in soilless peat-lite mixes include constant liquid fertigation with N at 200 to 300 mg·L⁻¹ (Ecke et al., 1990; Hartley, 1992). Excessive fertilization, poor drainage, insufficient irrigation, poor water quality, or a combination can all lead to a buildup of substrate salinity that can reduce plant growth. Leaching container substrates often is used to prevent substrate salt content from increasing to damaging levels (Richards, 1954). However, excessive leaching is undesirable because it may contaminate the environment with fertilizers (Biernbaum and Fonteno, 1989). Three ways to reduce fertilizer leaching are to reduce the leaching fraction (LF), the fertilization concentration, or the frequency of fertigation.

The LF is defined as the volume of leachate divided by the volume of irrigation solution applied. According to Nelson (1990) and Yelanich and Biernbaum (1993), a LF as high as 0.5 is common. Yelanich and Biernbaum (1993) reported that quality poinsettias were produced with a 0 LF and 100 mg·L⁻¹ N fertigation. Similarly, we found that poinsettia shoot dry mass with 50 mg·L⁻¹ N from a 20N-4.4P-16.6K fertilizer was 17% greater compared to those fertilized with N at 200 or 300 mg·L⁻¹ (Ku and Hershey, 1991a). However, we found that shoot dry mass increased as the LF increased from 0 to 0.4. Also, our plants were of better marketable quality with 200 and 300 mg·L⁻¹ than with 100 mg·L⁻¹ N fertigation. The lower rate produced plants that were less compact and had paler green foliage. In contrast, Dole et al. (1994) found that poinsettias receiving N at 250 mg·L⁻¹ from 20N-4.4P-16.6K fertilizer via top irrigation with a LF of 0.39 to 0.43 had a

greater shoot dry mass than those grown with N at 175 mg·L⁻¹.

Only a few N leaching studies on potted floral crops have specified the LF (Cabrera et al., 1993; Cox, 1985; Dole et al., 1994; Hershey and Paul, 1982; McAvoy, 1994; McAvoy et al., 1992; Yelanich and Biernbaum, 1993). Extensive studies on fate of applied fertilizer N were conducted on potted privet (*Ligustrum japonicum*) (Stewart et al., 1981) and potted geranium (*Pelargonium ×hortorum*) (Cox, 1985). Several other studies have evaluated fertilization concentration on N leaching and growth of potted begonia (*Begonia semperflorens*) (Haynes, 1982), chrysanthemum (*Dendranthema ×grandiflorum*) (Hershey and Paul, 1982; McAvoy, 1994), poinsettia (Dole et al., 1994), rose (*Rosa ×hybrida*) (Cabrera et al., 1993), and fern (*Nephrolepis exaltata*) (Conover and Poole, 1992) or determined N leaching from potted tropical foliage under different fertilization programs (Broschat, 1995).

For poinsettia, Yelanich and Biernbaum (1993) estimated that the N leached with 400 mg·L⁻¹ N fertigation at a 0.55 LF was ≈40-times higher than from plants that received 100 mg·L⁻¹ N fertigation at a 0.15 LF. In a vegetative poinsettia study, they reported that >50% of the applied N was leached at a 0.4 LF, regardless of the fertigation rate (Yelanich and Biernbaum, 1994). This amount of N leached from the container substrate may contribute significantly to environmental contamination with N.

Most leaching studies were conducted by applying a constant predetermined solution. However, this could result in variable LFs as found by McAvoy (1994). Considering the limited information on N leaching from potted poinsettia under a constant LF, this study was designed to evaluate two N ratios, two P fertigation rates, and three constant LFs on N leaching, N mass balance, and growth responses of potted poinsettia. A N fertigation rate of 210 mg·L⁻¹ was chosen based on our earlier study (Ku and Hershey, 1991a). Two N ratios (60% NO₃-N : 40% NH₄-N and 100% NO₃-N) were used. The 60% NO₃-N : 40% NH₄-N was chosen to duplicate the ratio in commercial 20N-4.4P-16.6K fertilizer. Also, Gaffney et al. (1982) reported an inferior growth of poinsettia when >50% of the total N is provided as NH₄-N. Thus, fertilizer NH₄-N level is recommended to be ≤50% of the total N (Ecke, 1986). The 100% NO₃-N was chosen to evaluate the maximum N

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¹Research associate; to whom reprint requests should be sent.

²Current address: Biology/Horticulture Dept., Prince George's Community College, 301 Largo Rd., Largo, MD 20772-2199.

leaching from potted poinsettia since nitrate is more readily leached than ammonium.

Materials and Methods

Terminal cuttings (7.5 cm long) of 'V-14 Glory' poinsettia were dipped in Hormodin no. 3 rooting powder and placed in Oasis strips (Smithers-Oasis, Kent, Ohio) on 9 Aug. 1991. The rooted cuttings were transplanted on 7 Sept., with one cutting per standard plastic pot (15 cm in diameter; 1.3 L). Cuttings were planted in Sunshine Mix 1 (Fisons Horticulture, Bellevue, Wash.), a commercial soilless substrate with Canadian sphagnum peat, perlite, wetting agent, and dolomitic limestone as the major components plus some starter nutrients. The substrate bulk volume was 1.3 L per pot, and the container capacity (CC) was 65% of the bulk volume. Bulk density was 110 g·L⁻¹. The initial (i.e., sample taken out of bag) substrate electroconductivity (EC) was 1.6 dS·m⁻¹ by saturated paste extract, and the initial pH was 6.0. The containers were spaced 38 × 38 cm on center and placed on raised benches in a glasshouse with air temperatures maintained at 19 to 24 °C during the day and 16 to 18 °C at night. Plants were pinched to 7 nodes on 20 Sept. A 9-h photoperiod was maintained from 21 Sept. through harvest by covering the plants with black cloth from 1700 to 0800 h each night. The initial dry mass of rooted cuttings averaged 1.0 g (SE = ±0.041, n = 4).

TREATMENTS. On 10 Sept., 12 treatments were established as factorial combinations: two N sources of 60% NO₃-N : 40% NH₄-N and 100% NO₃-N, two P concentrations of 7.8 and 23 mg·L⁻¹, and three LF of 0, 0.2, and 0.4. Throughout the experiment, plants received fertigation with a modified Hoagland Solution no. 1 (Hoagland and Arnon, 1950) at 210 mg·L⁻¹ N (Table 1). All treatments were replicated five times (one plant per replicate) and were arranged in a completely randomized design. The EC of the irrigation water was 0.3 dS·m⁻¹ at 25 °C, and the EC and pH of the fertigation solutions were 2.3 dS·m⁻¹ and 7.0 for the 100% NO₃-N solution and 2.7 dS·m⁻¹ and 7.2 for the 60% NO₃-N solution, regardless of P treatment.

All pots were thoroughly irrigated with tap water immediately after transplanting. Five unplanted pots filled with Sunshine Mix were similarly irrigated. No leachate was collected for this single irrigation. The study was initiated by thoroughly irrigating all

containers to CC with 1 L of their respective fertigation solutions on 10 Sept. Once at CC, the initial pot mass after irrigation (M_a) was determined, which was the second irrigation. The LF was not determined because the leachate was not collected. All the pots were set up to collect the leachate as described in Ku and Hershey (1992). The M_a was used to monitor the plant's daily evapotranspiration (ET) and to determine irrigation timing. The unplanted containers at CC were leached with a constant 200 mL tap water on all sampling dates, which was setup to determine the amount of N supplied by the substrate alone.

Before each fertigation, the pot mass before irrigation (M_b) was determined, and ET was estimated as ET = M_a - M_b. The amount of irrigation water to apply (V_a) was calculated as follows:

$$V_a = \frac{LF \times ET}{1 - LF} + ET \quad [1]$$

After ≈15 min, when leaching had ended, the leachate volume (V_l) was determined. Equation [1] ignored the increase in plant mass over time, which occurred with poinsettia (Ku and Hershey, 1991b). Thus, to avoid underestimating the ET, the equation was modified for the 0.2 and 0.4 LFs as follows, and the procedure for the 0 LF was that described in Ku and Hershey (1992). The predicted leachate volume (V_{lp}) was calculated as V_{lp} = target LF (0.2 or 0.4) × V_a. If V_l < V_{lp}, the target LF was not attained, so V_a was too small. To increase V_a, an additional volume of solution (V_{aa}) needed to be applied. To determine V_{aa}, an adjusted ET (ET_a) was calculated, (ET_a = ET + V_{lp} - V_l). Then V_{aa} was recalculated using ET_a in Eq. [1] and subtracting V_a,

$$V_{aa} = \frac{LF \times ET_a}{1 - LF} + ET - V_a \quad [2]$$

By using Eq. [2], the actual LFs were very similar to the target LFs of 0.2 and 0.4 (Fig. 1). There were a total of 26 fertigations during the 13-week study.

SAMPLING. Leachate samples from each replicate of the 0.2 and 0.4 LFs and the unplanted containers were collected for EC and pH determination. In addition, ≈30 mL of each leachate sample was immediately frozen at -5 °C for N analysis.

The plants in all treatments were harvested 13 weeks after the experiment began. Leaf and bract areas (petiole included) were measured with an area meter (LI-COR, Lincoln, Neb.). Plant fresh mass was determined by cutting the stem at the substrate surface and weighing the recently matured leaves, older leaves, bracts, and stems separately. The leaves and bracts were washed in tap water, rinsed with a Tween 80 [polyethylene (20) sorbitan monooleate] solution (2 drops per 1 L of tap water), and rinsed twice in deionized water. Total washing time did not exceed 1 min. All the plant parts were placed in separate clean paper bags and dried at 40 °C for dry mass determination. Recently matured and older leaf, bract, and stem samples were ground to pass through a 20 mesh screen in a Wiley mill (Arthur H. Thomas Co., Philadelphia, Pa.) and were stored in air-tight jars until analysis. Before analysis, all samples were redried at 65 °C for 24 h. At harvest, the container substrate was divided into upper, middle, and lower thirds. Leachate EC, leachate pH, substrate EC, and substrate pH were determined as in Ku and Hershey (1991b).

NITROGEN ANALYSIS. Kjeldahl-N of plant tissue was determined using the method of Bowman et al. (1988). Tissue NO₃-N extraction (Bowman et al., 1988) began by placing 0.5 g tissue and 15 mL deionized water in 16 × 150-mm glass test tubes. The tubes were shaken 15 min on a Thermomix shaker (B. Braun, Germany).

Table 1. Modified Hoagland nutrient solution no. 1 (Hoagland and Arnon, 1950).

Stock solution	Stock solution/nutrient solution (ml·L ⁻¹)			
	100% NO ₃ -N (mg·L ⁻¹)		60% NO ₃ -N : 40% NH ₄ -N (mg·L ⁻¹)	
	7.8 P	23 P	7.8 P	23 P
1 M Ca(NO ₃) ₂ ·4H ₂ O	5	5	4.5	4.5
1 M KNO ₃	5	5	---	---
1 M KH ₂ PO ₄	0.25	0.75	0.25	0.75
1 M MgSO ₄ ·7H ₂ O	2	2	2	2
50 mM FeNa EDTA ²	1	1	1	1
Micronutrients ³	1	1	1	1
1 M (NH ₄) ₂ SO ₄	---	---	3	3
0.5 M K ₂ SO ₄	---	---	5	5
1 M CaCl ₂	---	---	0.5	0.5

²Ferric-sodium salt of ethylene-diamine tetraacetic acid, instead of the Fe tartrate used in the original Hoagland recipe.

³Contains the following (in g·L⁻¹): 2.86 B(OH)₃, 1.81 MnCl₂·4H₂O, 0.22 ZnSO₄·7H₂O, 0.08 CuSO₄·5H₂O, and 0.02 H₂MoO₄·H₂O, (85% Molybdic acid).

Extracts were filtered using a serum filter.

Soluble N was extracted from the substrate (Keeney and Nelson, 1982) by adding 30 mL of 1 M KCl to 2 g of air-dried substrate in a 50-mL Erlenmeyer flask. The mixture was shaken for 1 h in a Thermomix shaker. Extracts were transferred to 16 × 150-mm glass test tubes and filtered using serum filters.

Leachate $\text{NO}_3\text{-N}$, tissue $\text{NO}_3\text{-N}$, and substrate soluble $\text{NO}_3\text{-N}$ were reduced with 30-mesh granular Zn (Carlson, 1986). The reduced $\text{NO}_3\text{-N}$, leachate $\text{NH}_4\text{-N}$, Kjeldahl-N, and substrate soluble $\text{NH}_4\text{-N}$ were determined with a Wescan ammonia analyzer (model 360; Alltech, Deerfield, IL).

RECOVERY AND DISTRIBUTION. The N recovery was calculated as follows:

$$\text{Percent N recovered} = \frac{\text{leachate N} + \text{final shoot N} + \text{final substrate N}}{\text{initial shoot N} + \text{initial substrate N} + \text{fertilization N}} \times 100$$

The initial shoot N averaged 26.3 mg, which represented the mean N content of five cuttings (stem and leaves) sampled on 7 Sept. The initial two leachates were not collected from the five unplanted containers setup with the study, and the leachate N concentration of the unplanted pots was near zero after 11 irrigations (2.8 L). Thus, to determine the actual amount of N supplied from the substrate, five new unplanted containers were leached with the same volume of tap water (2.8 L) as the previous unplanted pots. The N leached from the new unplanted containers was 114 mg and designated as the initial substrate N. The fertilization N included the total N applied from 10 Sept. to 6 Dec.

Leachate N included the N contributed from fertilizer and substrate leached between 16 Sept. and 6 Dec. Because leachate was not collected on 7 and 10 Sept., it was unknown how much of the substrate N and 210 mg N applied on 10 Sept. was lost through leaching at the initiation of the study. Final shoot N and final substrate N were determined at harvest on 13 Dec.

The percentage of N distributed in the leachate, shoot, or substrate was calculated as follows:

$$\text{Percent N distribution} = \frac{A}{\text{leachate N} + \text{final shoot N} + \text{final substrate N}} \times 100$$

Where A represented leachate N, final shoot N, or final substrate N.

STATISTICS. Data were analyzed using the SAS analysis of variance procedure ($\alpha = 0.05$) (SAS Inst., Cary, N.C.). Standard errors were calculated using the SAS means procedure. Main and interaction effect mean separations were by Fisher's least significant test (LSD, $\alpha = 0.05$). Plateau curve fits were performed using TableCurve, version 3.0 (Jandel, Corte Madera, Calif.).

Results and Discussion

PLANT RESPONSE. Phosphorus fertilization at 7.8 or 23 $\text{mg}\cdot\text{L}^{-1}$ had no significant affect on plant measurements at harvest (data not shown). The leaf and bract areas and dry masses of leaves, bracts, stems, and total shoots at the 0.4 LF were 17% to 42% greater than those at the two lower LF's (Tables 2 and 3). The difference in growth response among the LF's may have been due to salinity stress as suggested by substrate EC data.

At harvest, the substrate EC at the 0 LF was about twice the EC at the two higher LF's (Fig. 2). The substrate EC was highest in the upper third of the substrate and lowest in the middle third; however, the differences were not as large as reported by Agro and Biernbaum (1995), probably because 400 $\text{mg}\cdot\text{L}^{-1}$ N fertilization was used for the initial 58 d of their study and we used 210 $\text{mg}\cdot\text{L}^{-1}$ N fertilization for our 90-d study. The higher substrate EC in the lower

Fig. 1. The actual leaching fraction (LF) with P at 7.8 $\text{mg}\cdot\text{L}^{-1}$ (open symbols) and 23 $\text{mg}\cdot\text{L}^{-1}$ (filled symbols) for target LF's of 0.2 and 0.4. Each point represents a mean $\pm$ SE, $n = 5$. If not shown, the error bars lies within the symbol.

Table 2. Poinsettia leaves, bracts, stems, and total shoot dry masses at harvest.^z

	Dry mass (g)			
	Leaves	Bracts	Stems	Total
N fertilization (% $\text{NO}_3\text{-N}$)				
60	6.2	9.4	5.1	20.7
100	5.2	7.8	4.8	17.8
LSD _{0.05}	0.57	0.50	0.47	1.4
Leaching fraction				
0	5.0	7.5	4.5	17.0
0.2	5.5	8.6	4.9	19.0
0.4	6.6	9.8	5.4	21.7
LSD _{0.05}	0.70	0.61	0.57	1.7

^zData represents means, $n = 30$ for N fertilization and $n = 20$ for leaching fraction. There was no significant interaction effect.

third of the substrate was likely due to piston displacement of solution in the substrate (Ayers and Westcot, 1976). This pattern was less obvious at the 0.4 LF because a greater volume of solution was applied at each irrigation, which flushed more salts from the container substrate and minimized the salt accumulation in the lower third of the substrate. The higher substrate EC in the upper third of the substrate was possibly due to the upward migration of salts as a result of evaporation from the substrate surface (Ku and Hershey, 1992).

Substrate EC values of 2.5, 6.5, and 12 $\text{dS}\cdot\text{m}^{-1}$ were associated with 90%, 75%, and 50% of maximum poinsettia yields, respectively (Hartmann et al., 1988). Using the Hartmann et al. (1988) scale, the plant yields at the 0.4 LF should be 20% greater than

Table 3. Poinsettia leaf area, bract area, and recently matured leaves N concentration, and total leaf N content at harvest.^z

	Leaf area (cm ²)	Bract area (cm ²)	Recently matured leaf N concn (mg·g ⁻¹ , dry mass basis)	Total leaf N content (mg)
N fertigation (% NO ₃ -N)				
60	1470	4700	40.1	236
100	1320	3720	34.1	166
LSD _{0.05}	124	246	1.2	18
Leaching fraction				
0	1220	3460	36.0	169
0.2	1370	4230	37.0	195
0.4	1600	4930	38.3	241
LSD _{0.05}	152	301	1.4	22

^zData represents means, n = 30 for N fertigation and n = 20 for leaching fraction. There was no significant interaction effect.

Fig. 2. Substrate electroconductivity (EC) for 60% NO₃-N and 100% NO₃-N treatments at harvest for the upper (U), middle (M), and lower (L) thirds of the substrate. Each bar represents a mean $\pm$ SE, n = 10.

those at the 0 LF; however, the actual increase in yield from 0 to 0.4 LF was 29% in this study (Table 2, 3). Unlike a classic salinity study (Kofranek et al., 1956) where most salt is NaCl, the salts in the fertigation solution of this study were primarily fertilizer salts, and much of the salts were absorbed by the plants, so they only gradually built up in the substrate. Thus, although there was a decrease in yield in this study, as would be predicted based on a standard salinity study, the plants at the 0 LF were of good quality.

NITROGEN SOURCES. The total N concentration in the recently matured leaves of plants that received 60% NO₃-N fertigation was in the normal range of 4% to 6% (Ecke et al., 1990) (Table 3). Although the 100% NO₃-N fertigated plants had only 3.4% N in the recently matured leaves, the plants were of acceptable market

quality. The total N concentration in the recently matured leaves; leaf and bract areas (Table 3); and the leaf, bract, and total shoot dry masses (Table 2) with 60% NO₃-N fertigation were 11% to 26% more than with 100% NO₃-N fertigation. Similarly, Nell and Barrett (1985) reported that 'V-14 Glory' fertigated with 50% NO₃-N was 9% wider and had a 13% larger bract diameter than those fertigated with 100% NO₃-N. Also, the leaf N concentrations of 'Annette Hegg Supreme' received 10%, 50%, or 100% NH₄-N fertigation were 25% greater than those fertigated with

100% NO₃-N (Tsatsui and Aoki, 1981).

There are several possible explanations for the differences noted between the 60% and 100% NO₃-N fertigation. Differences may be due to substrate pH. The initial leachate pH of 5.5 was raised to ≥ 6.5 with 100% NO₃-N fertigation 40 d after study began, but was usually between 5.5 to 6.5 with 60% NO₃-N fertigation during the study (data not shown). At harvest, the substrate pH was 7.2 with 100% NO₃-N fertigation and 5.2 with 60% NO₃-N fertigation (Data not shown). This suggests that uptake of some nutrients could have been limited with the 100% NO₃-N fertigation because the substrate pH was higher than the recommended substrate pH range of 5.8 to 6.3 (Hartley, 1992). Another explanation for differences in growth between the N treatments is that due to the high leachability of nitrate, less nitrate remained for uptake compared to NH₄-N, which could be retained on the substrate cation exchange sites. Thus, the N potentially available for uptake between irrigations may have been greater with the 60% NO₃-N fertigation than with 100% NO₃-N fertigation. However, this explanation is not supported by our data. The leachate N contained at most 26% NH₄-N for the initial 30 d; thereafter, it was 1% to 3% (Fig. 3). Hershey and Paul (1982) and Cabrera et al. (1993) reported a similar trend. At harvest, the percentage of the total N that was present as NH₄-N recovered from the substrate with 60% NO₃-N fertigation was 0.35% at the 0 LF to 7% at the 0.4 LF. These results indicated that there was minimal NH₄-N retained on substrate cation exchange sites and that nearly all of the ammonium was nitrified. Lang and Elliot (1991) reported that the ammonium oxidation rate for an unplanted soilless mix composed of 1 sphagnum peat : 1 vermiculite : 1 perlite was 1.5 to 2 mmol·L⁻¹·h⁻¹ at pH 6.5. They found that the ammonium oxidation rate for planted containers was ≈ 1.8 -times higher than for unplanted containers, and the activity of nitrifying bacteria decreased as the substrate pH decreased. In this study, leachate from planted containers ranged in pH from 5.5 to 6.5 with 60% NO₃-N fertigation, indicating that the substrate environment was favorable for nitrification. Using the oxidation rate of 2 mmol·L⁻¹·h⁻¹ (Lang and Elliot, 1991), we estimated that it would take at most 2.3 h to nitrify the NH₄ at 84 mg·L⁻¹ in the 60% NO₃-N fertigation solution. Another explanation for the differences in growth between 60% and 100% NO₃-N fertigation is that the inclusion of NH₄-N in the N source might have increased the supply of organic N moving from roots to shoots (Elliot and Nelson, 1983). This explanation is in agreement with the leaf N content, which was 42% greater with 60% NO₃-N fertigation than with 100% NO₃-N (Table 3).

N LEACHING. The P fertigation of 7.8 or 23 mg·L⁻¹ did not affect

N leaching from either N source. Therefore, the N leaching data presented are the main effect means for the 100% and 60% $\text{NO}_3\text{-N}$ fertigation at each LF (Fig. 4).

Leachate N concentration ($\text{NO}_3\text{-N}$ and $\text{NH}_4\text{-N}$) at the 0.2 LF was greater than at the 0.4 LF (Fig. 4), as also reported by Cabrera et al. (1993) for roses, McAvoy et al. (1992) for poinsettia, and McAvoy (1994) for chrysanthemum. For the first 30 d, the leachate N concentration gradually increased to $300 \text{ mg}\cdot\text{L}^{-1}$ with 60% $\text{NO}_3\text{-N}$ fertigation and $360 \text{ mg}\cdot\text{L}^{-1}$ with 100% $\text{NO}_3\text{-N}$ fertigation. The leachate N concentration began to level off at $\approx 46 \text{ d}$ for the 0.2 LF and at $\approx 32 \text{ d}$ for the 0.4 LF. The leachate N concentration with 100% $\text{NO}_3\text{-N}$ fertigation averaged $700 \text{ mg}\cdot\text{L}^{-1}$ at the 0.2 LF and $430 \text{ mg}\cdot\text{L}^{-1}$ at the 0.4 LF. In contrast, the leachate N concentration with 60% $\text{NO}_3\text{-N}$ fertigation plateaued at $650 \text{ mg}\cdot\text{L}^{-1}$ at the 0.2 LF and at $380 \text{ mg}\cdot\text{L}^{-1}$ at the 0.4 LF. The plateau pattern also was found in the leachate EC data (Fig. 5) and in a potted chrysanthemum study (Hershey and Paul, 1982). The plateau state represents a steady-state, meaning the salt added to the containers (i.e., salt in fertigation solution) about equalled the salt leaving the containers (i.e., salt in leachate and absorbed by plants). The leachate N concentrations for all treatments remained higher than the applied N concentration of $210 \text{ mg}\cdot\text{L}^{-1}$, except during the initial 15 d with 60% $\text{NO}_3\text{-N}$ fertigation. The relative uptake of N and water by the plant determines the leachate N concentration (Hershey and Paul, 1982), meaning that the plant absorbed water at a relatively faster rate than it absorbed N. This result suggests that the N fertigation rate probably could be reduced without reducing plant growth.

NITROGEN RECOVERY AND DISTRIBUTION. The total N leached included substrate N and fertigation N between 16 Sept. to 6 Dec. (Table 4). The initial N in the substrate contributed little to the total N leaching from the planted containers. The N content in the unplanted containers was only 72 mg (16 Sept. to 6 Dec.), and there was no N leaching from unplanted containers 59 d after the study began (Fig. 4). This amounted to 3% to 8% of the total N leached from the planted containers, indicating that at least 92% of the leachate N was from fertilizer. The 210 mg N applied on 10 Sept. (second irrigation) represented 7% of the total fertigation N at the 0.4 LF and 14% at the 0 LF. The total fertigation N applied ranged from 1.6 g at the 0 LF to 33 g at the 0.4 LF (Table 4). The total N applied for both N treatments at the 0.4 LF was 2.2-times more than at the 0 LF.

Analysis of the shoot, leachate, and substrate accounted for 74% to 91% of the total N applied. There was a larger percentage of unrecovered N at the 0 LF. This was because a larger fraction of applied $\text{NO}_3\text{-N}$ that was not absorbed by the plants, remained in the substrate and was subjected to denitrification with a 0 LF as was reported by Stewart et al. (1981). The substrate water content before each irrigation at the 0 LF was 10% greater than the two higher LFs, suggesting the container environment at the 0 LF was more favorable for denitrification. Another explanation is that some of the unaccounted N was immobilized by substrate microbes or was in the roots. The substrate N content reported in this study only accounted for the soluble and exchangeable N. Kjeldahl digestion of the substrate and roots was not performed. Based on an 81-d solution culture poinsettia study (concurrent with this study), the shoot : root ratio at harvest was 3:1 for both N treatments, whereas Yelanich and Biernbaum (1993) reported poinsettia shoot : root ratio was 5:1 at a 0 LF and 7:1 at a 0.35 LF with $196 \text{ mg}\cdot\text{L}^{-1}$ N fertigation. Using the 3:1 ratio, the estimated root N content for this study was 78 mg N with 60% $\text{NO}_3\text{-N}$ and 64 mg N with 100% $\text{NO}_3\text{-N}$. Lastly, leachate from the initial two irrigations was not collected, thus a small percentage of the N was not recovered.

It is important to include both the percentages and the actual N mass in any discussion of N leaching. The percentage of N in the leachate at the 0.4 LF was 18% more than at the 0.2 LF (Fig. 6). This percentage suggests that there was not a large difference in N loss between the two LFs, but the N content indicated otherwise. The leachate N content at the 0.4 LF was twice that at the 0.2 LF. For example, for plants fertigated with 60% $\text{NO}_3\text{-N}$ fertigation, 51% N in the leachate with a 0.2 LF was equivalent to 1.01 g of N while 68%

Fig. 3. Leachate $\text{NH}_4\text{-N}$ concentration (open symbols) and leachate $\text{NO}_3\text{-N}$ concentration (filled symbols) for poinsettia that received 60% $\text{NO}_3\text{-N}$ fertigation. Each point represents a mean $\pm \text{SE}$, $n = 5$. If not shown, error bar lies within symbols.

Fig. 4. Leachate N concentration (open symbols) for unplanted container and 60% $\text{NO}_3\text{-N}$ and 100% $\text{NO}_3\text{-N}$ fertigations with leaching fractions (LFs) of 0.2 and 0.4. Cumulative N leached for 60% $\text{NO}_3\text{-N}$ and 100% $\text{NO}_3\text{-N}$ with LFs of 0.2 ($\blacktriangle$) and 0.4 ($\blacksquare$). Each point represents a mean $\pm \text{SE}$, $n = 10$. If not shown, the error bar lies within the symbol.

N in the leachate with a 0.4 LF equalled 1.97 g of N (Fig. 6, Table 4).

We calculated the amount of N leaching from potted poinsettia (Table 4). Using a suggested spacing of seven pots per square meter (i.e., 38 × 38 cm on center) for commercial production of 15-cm potted poinsettia (Ecke, 1986), the N leached was at least 6.4 g·m⁻² crop at the 0.2 LF and at most 14.8 g·m⁻² crop at the 0.4 LF. These N leaching losses are equivalent to annual N application rates for many field crops (California Fertilizer Association, 1980). The total amount of N leaching in this study was for a 13-week cropping cycle; however, greenhouse crop production is a continuous process. The N fertigation rate used in this study was lower than the recommended 250 or the 300 to 400 mg·L⁻¹ that some growers use during the initial few weeks after potting (Hartley, 1992). In addition, the LFs in this study were carefully maintained at 0, 0.2, or 0.4, but LFs as high as 0.5 are common if the application is not automatically controlled (Yelanich and Biernbaum, 1993). We found that at least 50% of the recovered N was in the leachate with 210 mg·L⁻¹ N fertigation (Fig. 6), which demonstrates that N is typically over applied during poinsettia production. Nitrogen leaching from greenhouse potted poinsettias could be a potential point source of pollution.

Premium marketable quality poinsettias were produced with 210 mg·L⁻¹ of 60% NO₃-N : 40% NH₄-N fertigation solution with 0.4 LF. Poinsettia dry mass was reduced for both N fertigations at

Fig. 5. Leachate electroconductivity (EC) for 60% NO₃-N and 100% NO₃-N treatments with leaching fractions (LFs) of 0.2 and 0.4. Each point represents a mean $\pm$ SE, n = 10. If not shown, error bar lies within symbols.

Table 4. Overall fertigation N applied, leachate N, shoot N, substrate N, and N recovered at harvest.^z

NO ₃ -N (%)	LF	Fertigation N (mg)	Leachate N (mg)	Shoot N (mg)	Substrate N (mg)	N recovered (%) ^y
60	0	1700	0	476	781	73.9
	0.2	2280	1010	521	447	86.7
	0.4	3270	1970	646	297	88.8
100	0	1620	0	328	881	74.8
	0.2	2250	1080	385	433	84.2
	0.4	3070	2050	421	313	90.9
LSD _{0.05}						
N ^x		107	76	36	36	2.2
LF		131	93	44	45	2.7
N × LF		185	130	62	63	3.8

^zData represents mean, n = 10.

^yPercent recovery = (leachate N + shoot N + substrate N) ÷ [fertigation N + initial substrate N (114 mg) + initial plant N (26.3 mg)].

^xNitrogen fertigation (N) and leaching fraction (LF).

the 0 and 0.2 LF, but plants were of good marketable quality. If excessive N leaching is a concern and a minimal reduction in quality is acceptable, then poinsettia could be grown with 210 mg·L⁻¹ and lower than a 0.4 LF if the irrigation water salinity is low. Alternatively, the N fertigation rate probably could be reduced to between 100 and 200 mg·L⁻¹ because 1) in a previous study, we found that 100 mg·L⁻¹ N fertigation produced the greatest shoot dry mass but produced plants of poorer quality than those with 200 or 300 mg·L⁻¹ N fertigation (Ku and Hershey, 1991a) and 2) under conditions of this study, the leachate N concentration was usually higher than the applied N concentration of 210 mg·L⁻¹. More recently, acceptable quality poinsettia was produced with a variable application rate, whereby the N fertigation started with 75 mg·L⁻¹ and was gradually increased to 150 mg·L⁻¹ with subirrigation (Rose et al., 1994).

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Fig. 6. Total N recovered and percentage N distributed in the leachate, shoot, and substrate for container-grown poinsettia at harvest. The percentage N distribution was calculated based on the total N recovered. Each bar represents a mean, $n = 10$.

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