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Root-medium Nutrient Concentration and Growth of Poinsettia at Three Fertilizer Concentrations and Four Leaching Fractions

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Abstract. **'V-14 Glory' poinsettias *(Euphorbia pulcherrima* Willd. ex Klotzsch) were fertilized at every irrigation with solutions containing 7, 14, or 28 mol N/m^3 at four leaching fractions (LFs) of 0, 0.1 to 0.2, 0.3 to 0.4, or 0.5 to 0.6 or with subirrigation. The N applied ranged from 44 to 464 mmol/pot applied over 12 to 25 irrigations. Medium NO_3-N and K concentrations and electrical conductivity were highest at the highest fertilizer concentration and lowest LF throughout cropping. Phosphorous concentration in the medium declined until week 12, when phosphoric acid was added for pH adjustment. Subsequently, medium P concentration was highest in treatments with the highest LF. Final shoot height, plant dry mass, and leaf area decreased as fertilizer concentration increased. Highest fresh mass, bract area, and shoot : root ratio were obtained with 14 or 28 mol N/m^3 and a 0.55 LF or with 7 mol N/m^3 and a 0.15 LF. Leaf N concentration was lower with subirrigation than with surface application. Leaf P and Mg were lower at higher LFs or with subirrigation, but leaf K was not influenced by the treatments.**

Several studies have been conducted to determine the concentration of fertilizer required for optimal growth and development of poinsettia. Shanks and Link (1956) recommended that a solution concentration of 66N-12P-9K (mol·m^{-3}) be applied once a week. Boodley (1970) reported that poinsettias fertilized weekly with 28.6 mol N/m^3 had a larger bract area than plants fertilized weekly with 57.2 mol N/m^3. In a review, Yelanich (1991) found commercial poinsettia fertilizer recommendations to range from 14.3 to 28.6 mol N/m^3, to be applied at every irrigation.

Leaching is commonly used to prevent soluble salts from accumulating in the medium during the application of liquid fertilizers to greenhouse crops. The volume of solution leached divided by the total solution applied is termed the leaching fraction (LF) (Hershey and Paul, 1982). The recommended LF is 0.1 (Mastalerz, 1977; Nelson, 1985), but it is not uncommon for growers using drip irrigation to have an LF >0.4 to 0.5 (George, 1989).

Leaching influences the concentration of nutrients in the medium and leachate. Hershey and Paul (1982) reported that the N concentration leached from a chrysanthemum *[Dendranthema ×grandiflorum* (Ramat.) Kitamura] root medium (average LF = 0.27) was affected by the fertilizer concentration (FC) applied and the time from planting. They also found that, at a low FC, the N concentration in the leachate was lower than that in the solution applied, but, at a higher FC, N concentration was higher and increased over time.

Kerr and Hanan (1985) found that for containers without plants at container capacity and that leached continuously, the efficiency of salt removal declined dramatically after a volume of 1 to 1.5 container capacities had been leached. They also determined that the concentration of salts in the applied solution did not affect the amount of salt removed from the pot during leaching, but affected the concentration of salt remaining in the pot after leaching.

Ku and Hershey (1991) found that, at a lower LF (0.1 and 0.2 LF), the electrical conductivity (EC) in the leachate increased over time and only with 0.4 LF did the EC of the leachate stabilize. They reported that the saturated medium extract EC of poinsettias grown with 21.4 mol N/m^3 applied with a 0, 0.1, 0.2, or 0.4 LF was 8.9, 7.3, 5.2, and 3.4 dS·m^{-1}, respectively, after 70 days. While the feasibility of lowering LF was demonstrated, the effect of fertilizer concentration was not investigated.

The volume and concentration of fertilizer applied, together with the volume of leachate, are important factors determining the amount of nutrients available to the plant (Nelson, 1986). However, the LF × FC interaction is not considered in most nutrient studies, and there are few reports of LF and FC effects together on medium nutrient concentration in a container crop. An understanding of the relationship between LF and FC is needed to minimize leaching. The relationship between leaching and subirrigation is also important for determining fertilization rates for subirrigation methods. The objectives of this experiment were to investigate how LF and FC influence medium nutrient concentration and poinsettia growth and to compare subirrigation with traditional top-watering methods.

Material and Methods

The treatments were arranged as a split plot, using the three fertilizer concentrations as the main plots and the five LFs and nine sampling dates as the subplots. There were three complete blocks for a total of 405 plants plus guard rows. One plant per treatment was selected randomly from each block at each sampling date, giving three replicates per sampling date. Medium concentration data over time were transformed to log(observed + 1) for analysis of variance, since sample variance increased over time.

Complete fertilizer solutions containing 7, 14, or 28 mol N/m^3 were made initially from calcium nitrate and potassium nitrate. These were changed on 22 Oct. (Week 9) to ammonium nitrate and potassium nitrate to lower the medium pH (Table 1). The water used to make the fertilizer solutions had an EC of 0.6 to 0.7 dS·m^{-1} and an alkalinity of 6.0 to 6.4 mol·m^{-3} (300 to 350 mg·liter^{-1} $CaCO_3$).

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Table 1. Nutrient concentrations (mol·m^{-3}) and electrical conductivity (EC) (dS·m^{-1}) of the fertilizer solutions applied.

	Fertilizer N (mol·m^{-3})					
	22 Aug.–22 Oct.^{z}			22 Oct.–12 Dec.^{z}		
Criterion	7	14	28	7	14	28
Total N	7.2	14.4	28.9	7.3	14.7	29.3
NO_3-N	6.8	13.7	27.3	5.0	10.0	20.0
NH_4-N	0.4	0.8	1.5	2.3	4.7	9.3
K	2.7	5.3	10.7	2.7	5.3	10.7
Ca^y	3.9	5.8	9.6	2.00	2.00	2.00
EC	1.42	2.08	3.40	1.67	2.56	3.73

^{z}Stock solutions for 22 Aug. to 22 Oct. were made from fertilizer-grade calcium nitrate and potassium nitrate. Stock solutions for 22 Oct. to 12 Dec. were made from potassium nitrate and ammonium nitrate. The fertilizer-grade calcium nitrate [5 $Ca(NO_3)_2$–NH_4NO_3–10 H_2O] contained ammonium nitrate. The water used to make the fertilizer solution contained Ca at 2 mol·m^{-3} and Mg at 1.7 mol·m^{-3}.

Phosphoric acid (3.9 mol·m^{-3}) was added to the stock solution on 20 Nov. (Week 13) to lower the pH further. After 12 Dec., plants received only tap water, which was applied as needed by subirrigation. The nutrient solutions were applied independently to each treatment when the total mass of a representative pot, medium, and plant had dried to 700 to 750 g.

The four LF treatments were established by adding known volumes of solution to established plants and measuring the volume of leachate; 500, 750, and 1250 cm^3 of solution were necessary to achieve the 0.1 to 0.2 (0.15), 0.3 to 0.4 (0.35), and 0.5 to 0.6 (0.55) target LF. The 0 LF and subirrigation treatments received 300 cm^3 of solution at each irrigation, based on the amount of solution the medium could absorb by subirrigation. The nutrient solution was applied to the subirrigation treatments by adding 300 cm^3 of solution to an 18-cm-diameter tray placed under each container.

The experiment was conducted in East Lansing, Mich., in a well-ventilated glasshouse with constant air circulation and concrete floors. Rooted cuttings of ‘V-14 Glory’ *Euphorbia pulcherrima* were planted on 19 Aug. 1988 in plastic pots 15 cm wide at the top × 12 cm high (pot volume = 1580 cm^3). Plants were pinched to six nodes on 6 Sept. 2-Chloroethyl- *N,N,N* -tri-methylammonium chloride (chlormequat) was applied as a foliar spray at 1.5 kg·m^{-3} on 26 Sept. to control height. The average greenhouse temperature during theexperiment was 19.7C (21.0C day and 18.7C night). On 12 Dec. 1988, 45 plants were put in paper sleeves for 24 h to simulate shipping and placed in a postproduction environment (20C with continuous light at an average photosynthetic photon flux of 0.67 mol·m^{-2}·day^{-1} from cool-white fluorescent lamps) until 3 Jan. 1989, when the experiment ended.

The medium was a commercially available root medium consisting of sphagnum peat, coarse vermiculite, and perlite (Baccto Professional Growers Mix, Michigan Peat Co., Houston). The bulk medium volume was 0.332 m^3 and the pots of medium initially had a bulk density of 200 kg·m^{-3}, a container capacity of 0.001 m^3, a water porosity of 0.64 m^3·m^{-3}, and an air porosity of 0.15 m^3·m^{-3}. Medium samples were collected every 2 weeks for 16 weeks, beginning after planting. The sample consisted of the entire medium in the pot, except for the subirrigated treatments, in which the surface layer (1 to 2 cm) without roots was scraped off and discarded. The top layer was removed from subirrigation treatments to approximate production practices and to allow better comparison of the 0 LF and subirrigation treatments. The nutrients in the medium were extracted with distilled water using the saturated media extraction method (Warncke, 1986). Medium pH was determined by inserting the pH electrode directly into the saturated medium before extraction. Nitrate-N, EC, P, K, and Ca were determined from the extracted solution. Nitrate-N concentration was determined using an ion-specific electrode. EC, temperature corrected to 25C, was determined using a platinum electrode. Potassium, Ca, and P concentrations were determined by the Michigan State Univ. soil testing laboratory. Potassium concentration was determined by emission spectrometry, Ca concentration by atomic absorption, and P concentration colorimetrically by the ascorbic acid method (Knudsen and Beegle, 1988). The medium initially had a pH of 5.6 and an EC of 1 dS·m^{-1}.

Shoot height, fresh mass, dry mass (dried in a forced draft oven at 60C for 2 to 3 days), leaf and bract area (Delta-T Devices, Cambridge, England), and leaf count were recorded at 2-week intervals. The roots were collected by shaking off the loose medium and washing them with water. Mature, fully expanded green leaves were collected after 16 weeks for elemental analysis. Shoot : root ratio was determined by dividing the shoot dry mass by the root dry mass. Yellow leaves and necrotic spots on the bracts of plants placed in the postproduction environment were counted on 3 Jan.

Results

Fertilizer applications. The N applied ranged from 44 to 464 mmol/pot and the number of irrigations from 12 to 25 (Table 2). Subirrigated plants received five more irrigations than 0 LF top-watered plants.

Nutrient concentrations in medium. Nitrate-N and K concentrations and EC in the medium at the 28 mol N/m^3 FC were higher at a higher LF than at a lower LF at Week 2 (Fig. 1, Table 3). Treatment differences at week 2 are not apparent in Fig. 1 due to the scaling. For example, at 28 mol N/m^3, the medium EC was 1.35, 1.47, 1.77, and 1.92 dS·m^{-1} for the 0.0, 0.15, 0.35, and 0.55 LFs. Nitrate-N concentration and EC at Week 4 and K and Ca concentration at Weeks 4 and 6 increased with a higher FC but were not influenced by LF. Nitrate-N and EC after Week 6 and K and Ca concentrations after Week 8 decreased at a higher LF. There was an unexpected decrease in medium K concentration in all treatments and in medium Ca concentration at the high FC and at 0 and 0.15 LFs at Week 14. The 0 LF and 0.15 LFs at each FC did not differ significantly for NO_3-N, EC, K, and Ca during most of the experiment. Medium pH, NO_3-N, K, and Ca concentrations, and EC were above recommended root-medium values, except at 7 mol N/m^3 with a 0.35 or 0.55 LF or at 14 mol N/m^3 with a 0.55 LF at Week 16.

Medium P concentration was not adjusted until week 12, when phosphoric acid was added to control medium pH. Medium P concentration decreased until Week 8, remained stable until Week 12, then rose until Week 16 (Fig. 1); it remained lower at a higher LF than at a lower LF from Week 2 until Week 8 (Fig. 1). After adding phosphoric acid, the P concentration was highest in the 14 and 28 mol N/m^3 treatments, which had the most leaching, and was lowest in treatments that were not leached.

Medium pH gradually rose from planting until Week 10 in all treatments, with the largest increase occurring at the highest LF (Fig. 1), then fell when ammonium nitrate was substituted for calcium nitrate and phosphoric acid was added. The pH decline was most rapid at higher LFs in the 14 and 28 mol N/m^3 treatments, but not in 7 mol N/m^3 treatments. Medium pH at the final harvest ranged from 5.4 to 6.6.

Similar medium nutrient concentrations were obtained with different FC and LF combinations. For example, the medium NO_3-N concentration for a 0.15 LF with a FC of 14 mol N/m^3 (1.4 g/pot N applied) resembled that for a 0.55 LF with a FC of 28 mol

Table 2. Total quantity of N applied, number of fertilizer applications (FAs), poinsettia growth characteristics, and leaf nutrient concentration 16 weeks after planting for leaching fractions (LFs) of 0, 0.15, 0.35, and 0.55 and fertilizer concentrations (FCs) of 7, 14, and 28 mol N/m^3.

			Shoot						Leaf				
				Fresh	Dry	Shoot :	Leaf	Bract					
	N	FA	Ht	mass	mass	root	area	area	N	P	K	Ca	Mg
Treatment	(mmol)	(no.)	(cm)	(g)	(g)	ratio	(m^2)	(m^2)	(mol·kg^{-1} dry mass)				
FC = 7 mol N/m^3													
Subirrigation	54	25	23.5	139	19.3	3.92	0.141	0.216	3.26	0.10	1.00	0.20	0.26
LF													
0.00	44	20	23.0	126	17.1	6.39	0.141	0.236	3.59	0.13	0.96	0.19	0.29
0.15	57	16	27.5	157	20.6	5.32	0.148	0.306	3.42	0.13	1.01	0.21	0.30
0.35	81	16	26.0	139	18.4	5.00	0.140	0.267	3.48	0.11	0.98	0.21	0.26
0.55	152	17	23.5	129	16.6	5.91	0.123	0.244	3.33	0.10	1.01	0.25	0.25
FC = 14 mol N/m^3													
Subirrigation	103	24	23.8	125	16.4	4.94	0.135	0.230	3.29	0.11	1.02	0.21	0.26
LF													
0.00	84	19	23.2	110	15.3	5.29	0.117	0.214	3.59	0.13	1.01	0.24	0.31
0.15	100	15	25.0	127	16.8	6.82	0.134	0.217	3.62	0.14	0.98	0.18	0.27
0.35	161	16	24.2	132	17.6	7.33	0.130	0.257	3.55	0.12	1.09	0.24	0.26
0.55	250	15	24.5	148	19.8	4.68	0.139	0.270	3.50	0.10	0.97	0.26	0.24
FC = 28 mol N/m^3													
Subirrigation	163	20	21.3	110	14.3	4.87	0.108	0.221	3.31	0.10	1.05	0.24	0.23
LF													
0.00	124	15	22.2	92	12.4	5.67	0.094	0.132	3.48	0.17	1.05	0.29	0.33
0.15	157	12	21.2	84	11.3	5.79	0.088	0.150	3.59	0.13	1.05	0.27	0.28
0.35	257	12	22.8	119	15.7	5.85	0.113	0.234	3.52	0.13	1.05	0.27	0.26
0.55	464	13	24.7	141	18.6	4.23	0.125	0.269	3.38	0.10	1.02	0.28	0.20
FC			*	**	**	NS	**	**	NS	NS	NS	**	NS
LF			NS	*	NS	**	NS	**	**	***	NS	**	***
FC × LF			NS	*	NS	*	NS	**	NS	**	NS	NS	**

NS,*,**,***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

N/m^3 (6.5 g/pot N applied).

Plant growth and nutrient levels. Final shoot height, total dry mass, and leaf area decreased at a higher FC (Table 2) but were not significantly affected by LF. Shoot fresh mass and bract area of plants receiving 14 or 28 mol N/m^3 was highest at a higher LF, but, when 7 mol N/m^3 was applied, response was highest with a 0.15 LF. Bract area of subirrigated plants was larger than that of nonleached, top-watered plants only at 28 mol·m^{-3} N. Shoot : root ratio was highest when 14 mol N/m^3 was applied with a 0.35 LF and was lowest when 7 mol N/m^3 was applied by subirrigation (Table 2). The percent dry mass and leaf count were not significantly affected by treatments (data not shown).

Leaf N concentration at Week 16 was not affected by FC (Table 2). Leaf P and Mg concentrations were generally lower with subirrigation and at a higher LF. Leaf Ca concentration was generally higher at a higher LF and higher FC. Leaf nutrient concentrations for subirrigation treatments were lower than in 0 LF top-watered plants, resembling those in the high-LF plants. Leaf K concentrations were not influenced by LF or FC.

Postproduction. The number of chlorotic leaves (average two per plant) or necrotic spots or bract margins (average five per plant) after 3 weeks in the postproduction environment were not affected by treatments.

Discussion

Leaching affected medium nutrient concentrations, even when the same solution concentration was applied. Thus, fertilizer recommendations for greenhouse potted plants should include the fertilizer concentration to apply and the method of application and the desired medium nutrient level.

There were few significant differences between a 0 LF and the normally recommended 0.15 LF for NO_3-N, K, and Ca concentrations and EC in the medium at each of the sampling dates. Leaching fractions >0.35 were needed to maintain EC in the accepted ranges when the commonly recommended FC of 14 mol N/m^3 was applied. The apparent requirement for higher than recommended LFs may explain why LFs >0.4 have been used with drip-irrigation systems (George, 1989). The effect of LF was similar for all three FCs when the Week 16 EC data were normalized by dividing the mean EC by the 0 LF mean EC at each FC (Fig 2). The consistent effect of LF at each FC supports Kerr and Hanan's (1985) conclusion that the applied solution concentration does not influence salt removal.

Our findings support results reported by Ku and Hershey (1991). They found that a LF of 0.40 was necessary to maintain a near constant medium EC at a single fertilizer concentration. It may be important to note that the methods used by Ku and Hershey were different from those reported here; they applied a single fertilizer concentration at 4 LFs at regular time intervals. The volume applied was adjusted to maintain a constant LF. In our research, the volume applied was kept constant and application time was determined gravimetrically. All treatments were watered independently.

Using our method, the LF and the number of container capacities leached (Kerr and Hanan, 1985) remained constant. With the method of Ku and Hershey, the LF remained constant but the volume leached relative to the container capacity fluctuated. For

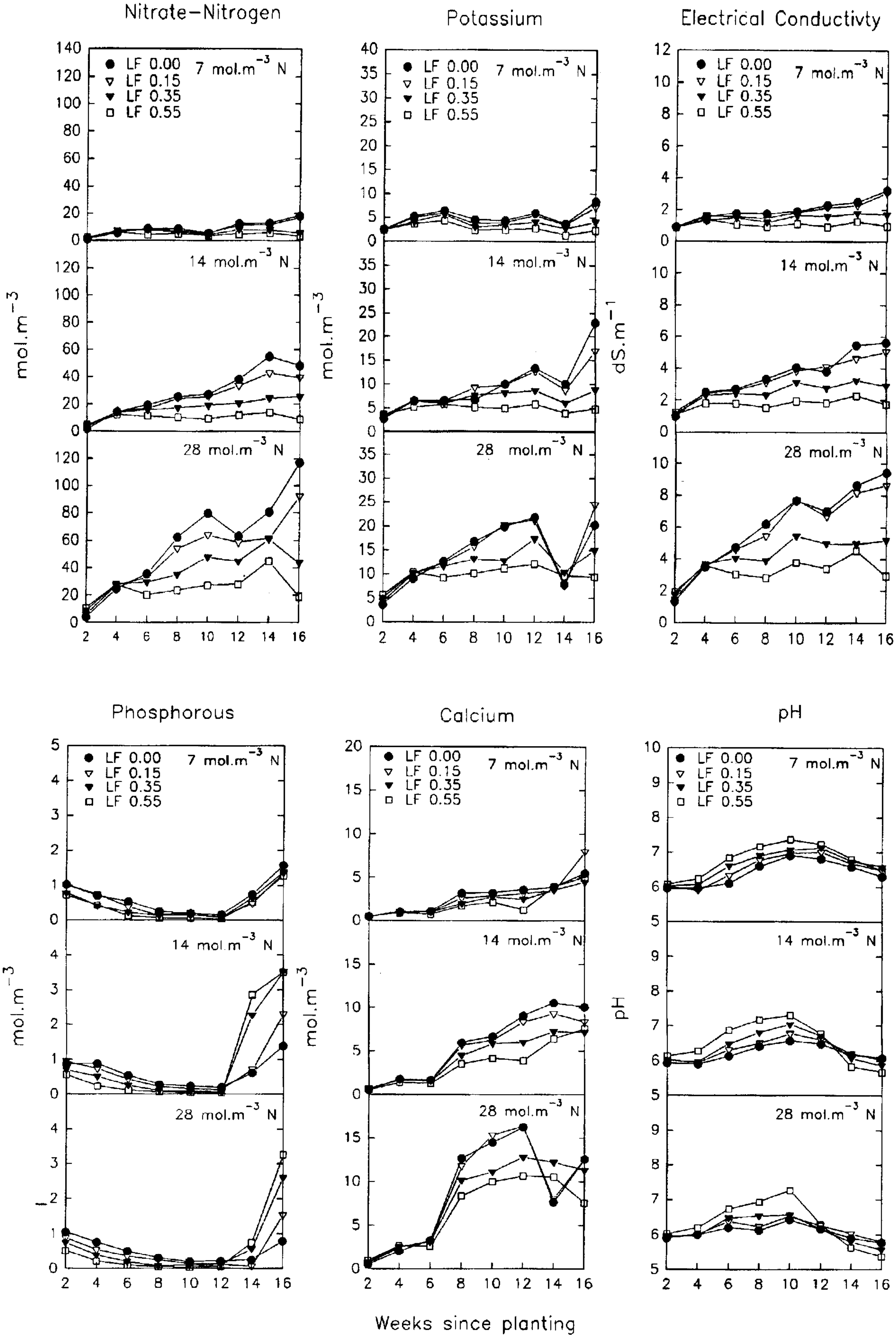

Fig. 1. Medium nitrate-N, K, P, and Ca concentrations and electrical conductivity and pH at 2-week intervals since planting.

Table 3. Summary of analysis of variance and selected contrasts by week for the log(observed + 1) transformed root-medium nutrient concentrations, electrical conductivity (EC), and pH.

		Sampling week							
Criterion	Effect[z]	2	4	6	8	10	12	14	16
NO_3-N	FC	***	**	***	***	***	***	***	**
	LF	***	NS	***	***	***	***	***	***
	FC × LF	***	NS	NS	*	*	NS	*	NS
	0 vs. 0.15 LF	***	NS	*	NS	NS	NS	*	NS
	0 vs. 0.35 LF	***	NS	**	***	**	***	***	***
K	FC	**	*	NS	**	***	***	***	***
	LF	**	**	**	*	***	***	***	**
	FC × LF	**	**	NS	NS	NS	NS	***	NS
	0 vs. 0.15 LF	*	NS	NS	NS	NS	NS	NS	NS
	0 vs. 0.35 LF	**	NS	NS	NS	***	***	**	***
EC	FC	***	**	**	***	***	**	***	***
	LF	**	NS	***	***	***	***	***	***
	FC × LF	**	NS	NS	*	NS	NS	NS	NS
	0 vs. 0.15 LF	**	NS	NS	*	NS	NS	*	NS
	0 vs. 0.35 LF	**	NS	*	***	**	**	***	***
P	FC	NS	NS	NS	NS	NS	*	*	**
	LF	***	***	***	***	**	***	***	***
	FC × LF	NS	NS	NS	NS	NS	NS	***	***
	0 vs. 0.15 LF	NS	NS	***	**	*	***	NS	**
	0 vs. 0.35 LF	**	***	***	***	**	***	***	***
Ca	FC	NS	**	***	**	**	***	**	**
	LF	NS	NS	**	***	***	***	NS	**
	FC × LF	NS	**	NS	NS	NS	NS	**	NS
	0 vs. 0.15 LF	NS	NS	NS	NS	NS	NS	NS	NS
	0 vs. 0.35 LF	NS	NS	NS	***	*	***	NS	*
pH	FC	**	NS	NS	**	**	***	**	**
	LF	***	***	***	***	***	***	**	***
	FC × LF	NS	NS	NS	**	**	**	**	***
	0 vs. 0.15 LF	**	NS	**	**	*	**	NS	NS
	0 vs. 0.35 LF	**	NS	***	***	***	***	NS	NS

[z]FC = fertilizer concentration, LF = leaching fraction.
NS,*,**,***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

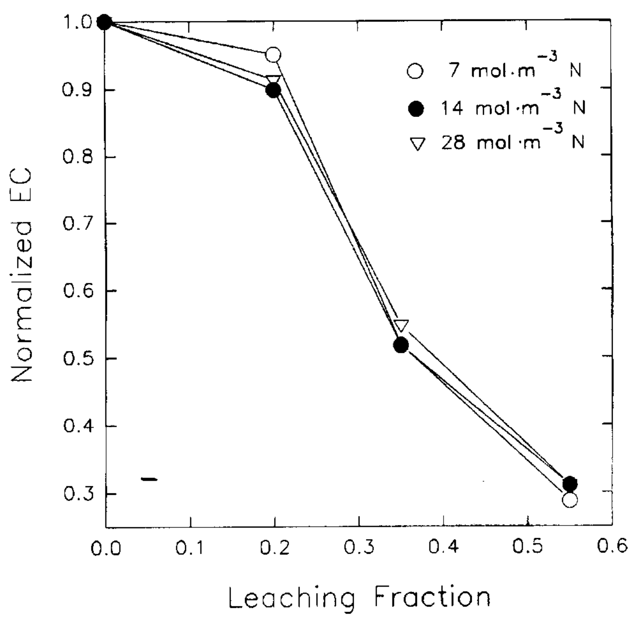

Fig. 2. Normalized mean medium electrical conductivity (EC) at 16 weeks after planting as influenced by leaching fraction (LF) and fertilizer concentration (FC). The mean (n = 3) medium ECs at each of the three FCs were divided by the maximum EC (0 LF) for that FC.

example, if there was 400 ml of available water, a 0.25 LF could occur with 400 ml applied and 100 ml leached, or 200 ml applied and 50 ml leached, or 100 ml applied and 25 ml leached. However the container capacities leached would have varied from 0.25 to 0.06, since the volume of leachate was different. The difference in methods could be important and should be considered in future research.

Subirrigated plants were similar in fresh and dry mass, height, and leaf area to the top-irrigated treatments with a 0 LF. In fact, nutrient concentrations in subirrigated media (data not shown) were similar to those with 0 and 0.15 LFs. Medium nutrient concentration of subirrigated plants were expected to be lower than those of top-watered plants, since the top layer of medium, which presumably contained accumulated fertilizer (Biernbaum et al., 1991), was removed from the former. One possible explanation was that the subirrigated plants were fertilized five times more than the top-watered plants and received more fertilizer.

Adequate medium fertility levels (Warncke and Krauskopf, 1983) were maintained using 7 mol N/m^3, less than half the commonly recommended N concentration, even at the highest LF. Commonly recommended FCs may supply excessive nutrients, requiring either leaching or periodic irrigation with water to reduce medium nutrient concentration. In two recently published papers (Bierman et al., 1991; Dole and Wilkins, 1990) in which 14 mol N/m^3 was applied to poinsettias grown in peat-based media, weekly irrigations with tap water were used to maintain acceptable medium nutrient concentrations. Fertilization recommendations should be based on desired medium nutrient levels, rather than on applied solution FCs.

Medium nutrient concentrations immediately following planting of poinsettia is a common concern (Sheldrake, 1987). Applied solution concentrations of 21 to 28 mol N/m^3 often are recommended to raise medium nutrient levels quickly. No detrimental effects on dry mass or leaf area were observed in early (data not shown) or late samples (Table 2) in the 7 mol N/m^3 treatments in this experiment, and medium N concentrations did not reach the reported optimal range (Warncke and Krauskopf, 1983) until Week 4.

From an environmental perspective, if good water is available, leachate produced in poinsettia production can be reduced by limiting the LF and lowering the FC. Plants cultured with a 0 LF and 7 mol N/m^3 FC were similar to or larger than plants grown at a higher FC and LF. Using a 0 LF and a 7 mol N/m^3 FC, 0.04 $kg\cdot m^{-2}$ (404 $kg\cdot ha^{-1}$) would be applied annually, based on a density of 20 plants/m^2 and 52 weeks of poinsettia production. This is one-tenth of the rate estimated for greenhouse chrysanthemum production by Nelson (1985) and is closer to the rate applied to other annual agricultural crops.

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