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Growth Response, Nutrient Leaching, and Mass Balance for Potted Poinsettia. II. Phosphorus

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Abstract. **Poinsettias (*Euphorbia pulcherrima* Willd. ex Klotzsch 'V-14 Glory') grown as single-pinched plants and received constant fertigation of Hoagland solution with N at 210 mg·L^{-1} of 100% NO_3-N or 60% NO_3-N : 40% NH_4-N; P at 7.8 and 23 mg·L^{-1}; and leaching fractions (LFs) of 0, 0.2, or 0.4. The P at 23 mg·L^{-1} used in this study was about half the P concentration typically provided from a 20N–4.4P–16.6K fertilizer at 200 mg·L^{-1} N fertigation. The total P applied via fertigation ranged from 51 mg at the 0 LF to 360 mg at the 0.4 LF. The leachate P concentration ranged from 0.2 to 46 mg·L^{-1}. With P at 7.8 mg·L^{-1}, the percentage of total P recovered in the leachate was 6% to 7%. At 23 mg·L^{-1} P fertigation, however, the total P recovered in the leachate with 60% NO_3-N treatment was 2-times greater than with 100% NO_3-N treatment. This result is attributed to a lower substrate pH, which resulted from NH_4-N uptake and nitrification processes with 60% NO_3-N fertigation. The P concentration in the recently matured leaves with 7.8 mg·L^{-1} P fertigation was in the normal range of 0.3% to 0.6%. Fertigation P can be reduced by up to 80% and still be sufficient for producing quality poinsettias. Reducing the fertigation P concentration is beneficial because it reduces P leaching, reduces fertilizer costs, and reduces luxury consumption.**

Leaching is a common practice in the greenhouse industry today; however, it is undesirable because it may contaminate the environment with fertilizers (Biernbaum and Fonteno, 1989). There is increasing interest in fertilizer contamination of the environment; three ways to reduce fertilizer leaching are to reduce the leaching fraction (LF), the fertilizer 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.

Phosphorus runoff into surface water increases eutrophication (Nelson, 1990), which increases aquatic plant growth, depletes the water's oxygen level, changes the pH, and alters the plant species composition (Sharpley et al., 1994). Phosphorus leaching from greenhouse crops may be an important point source of fertilizer pollution.

The recommended N fertigation rate for potted poinsettias grown in peat-lite mixes is 200 to 300 mg·L^{-1} (Ecke et al., 1990; Hartley, 1992). If a 250-mg·L^{-1} N fertilization rate is used, there could be P at 36 to 117 mg·L^{-1} provided by some of the typical complete fertilizers (Hartley, 1992). In addition, some of the commercial soilless mixes are amended with superphosphate as a starter nutrient.

Most P leaching experiments with soilless substrate were conducted in unplanted containers (Bilderback, 1990; Bunt, 1974, 1988; Marconi and Nelson, 1984; Yeager and Barrett, 1984, 1986). Most of these studies used a LF of 1 (Bunt, 1974; Marconi and Nelson, 1984; Yeager and Barrett, 1984, 1986) (i.e., the irrigation volume equalled the leachate volume). Few studies have investigated P leaching from planted containers, and the LFs either were not mentioned or the application volume was maintained at a constant level at each irrigation (Havis and Baker, 1985; Haynes, 1982; Prasad and Woods, 1971) or high LF of 1 was used (Conover and Poole, 1992). Most studies on P leaching in unplanted and planted containers indicated that P was highly leachable in soilless substrates.

Two studies on poinsettia evaluated the P level in the substrate over the crop cycle. Yelanich and Biernbaum (1993) reported potted poinsettia with an initial substrate P concentration of 31 mg·L^{-1} decreased to a negligible amount by week 6. Superphos-

Table 1. Phosphorus concentrations in recently matured leaves for potted poinsettia at harvest.[z]

NO_3-N (%)	P (mg·L^{-1})	LF	P concn (mg·g^{-1}, dry mass basis)
60	7.8	0	3.2
		0.2	3.4
		0.4	3.8
60	23	0	5.9
		0.2	6.8
		0.4	7.2
100	7.8	0	3.3
		0.2	3.1
		0.4	3.5
100	23	0	5.3
		0.2	6.1
		0.4	7.1
$LSD_{0.05}$			
N[y]			0.017
P			0.017
LF			0.021
N × P			0.024
N × LF			0.030
P × LF			0.030
N × P × LF			0.042

[z]Data represents mean, n = 5.
[y]N fertigation (N), P rate (P), and leaching fraction (LF).

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phate was their primary P fertilizer source and fertigation P w not applied until 13 weeks after their study began. Another study used triple superphosphate (0N–20P–0K) with P at 1.55 to 6.21 $kg \cdot m^{-3}$ and 46 $mg \cdot L^{-1}$ via fertigation (Whipker and Hammer, 1994). They reported an initial rapid decrease in the substrate P level.

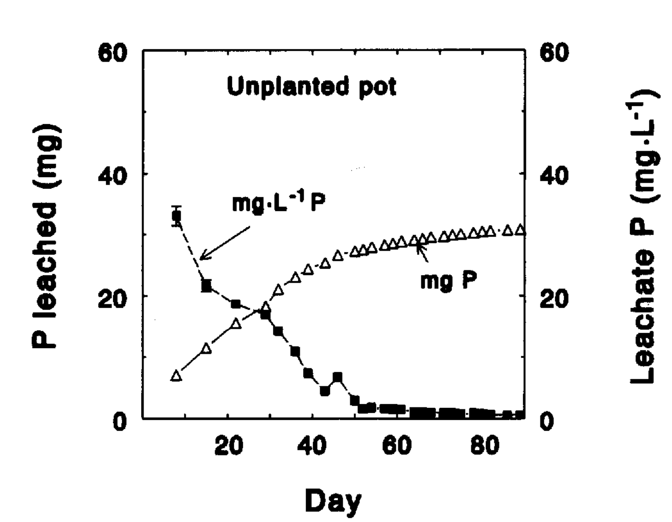

Fig. 1. Leachate P concentration (filled symbols) and cumulative P leached (open symbols) from unplanted containers that received 200 mL tap water at each irrigation. Each point represents a mean ± SE, n = 5. If not shown, the error bar lies within the symbol.

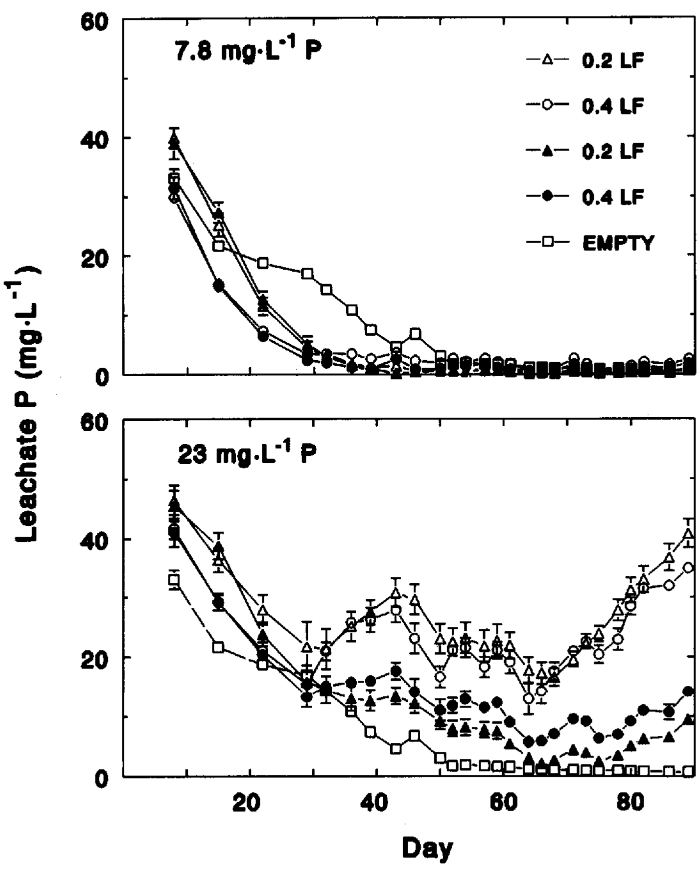

Fig. 2. Leachate P concentration for 7.8 and 23 $mg \cdot L^{-1}$ P treatments with N fertigations of 60% NO_3-N (open symbols) and 100% NO_3-N (filled symbols), and leaching fractions LFs of 0.2 and 0.4. Each point represents a mean ± SE, n = 5. If not shown, the error bar lies within the symbol.

Considering the limited information on P leaching from potted poinsettia, this study was designed to evaluate P leaching, P mass balance, and growth of potted poinsettia with two P levels, two N ratios, and three constant LFs. Our study used lower than normal P fertigation levels with P at 7.8 and 23 $mg \cdot L^{-1}$ for two reasons. First, the N : P ratio from a typical 20N–4.4P–16.6K fertilizer is 4.5:1; however, the deficiency critical nutrient levels in recently matured poinsettia leaves are 3.5% for N and 0.15% for P (Ecke et al., 1990) for a N : P ratio of 23:1. Second, luxury consumption of P by poinsettia was found in our preliminary study and appears common (Ku, 1988; Tsatsui and Aoki, 1981).

Materials and Methods

Most of the materials and methods are exactly as those described in the previous companion paper (Ku and Hershey, 1997).

Treatments. On 10 Sept., 12 treatments were established as factorial combinations of two N sources of 60% NO_3-N : 40% NH_4-N and 100% NO_3-N; two P concentrations of 7.8 and 23 $mg \cdot L^{-1}$; and three LFs of 0, 0.2, and 0.4. Throughout the experiment, plants received fertigation with a modified Hoagland Solution no. 1 (Hoagland and Arnon, 1950) with N at 210 $mg \cdot L^{-1}$. All treatments were replicated five times (one plant per replicate) and arranged in a completely randomized design. The electroconductivity (EC) of the irrigation water was 0.3 $dS \cdot m^{-1}$ at 25 °C, and the EC and pH of the fertigation solutions were 2.3 $dS \cdot m^{-1}$ and 7.0 for the 100% NO_3-N solution and 2.7 $dS \cdot m^{-1}$ and 7.2 for the 60% NO_3-N solution, regardless of P treatment.

Sampling. Leachate samples from each replicate of the 0.2 and 0.4 LF treatments and unplanted containers were collected for analysis of pH and P. At harvest, leaf and bract areas and fresh and dry masses of younger and older leaves, bracts, and stems were determined. Tissue samples for P analysis were prepared as described in the previous companion paper (Ku and Hershey, 1997). At harvest, air-dried container substrates were ground to pass through a 40-mesh screen in a Willey mill (Arthur H. Thomas Co., Philadelphia) and stored in air-tight jars until analysis.

Tissue samples (0.25 g) were ashed in a muffle furnace (General Signal Lindberg, Watertown, Wis.) for 3 h at 500 °C. Ashed samples were dissolved in 5 mL of 20% (v/v) HCl and filtered through Whatman no. 41 filter paper (Whatman Intl., Springfield Mill, Maidstone, Kent, England) and diluted to 50 mL with deionized water.

Bowman's (1988) procedure was used to extract total P in the substrate. The P concentration in leachate, plant parts, and substrate was analyzed colorimetrically (Watanabe and Olsen, 1965) with a spectrophotometer (model 390; Sequoia Turner Corp., Mountain View, Calif.).

Recovery and distribution. The P recovery was calculated as follows:

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

For the percent P recovery calculation, the initial shoot (stem and leaf) P content was 7.5 mg (SE ±0.65, n = 4), which was sampled on 7 Sept. The total P of Sunshine Mix 1 determined by a total P digestion procedure (Bowman, 1988) was 79 mg (SE ±1.6, n = 5), and this amount was designated as the initial substrate P content. The fertigation P included total P applied from 10 Sept. to 6 Dec.

Final shoot P and final substrate P was determined at harvest on 13 Dec. Leachate P included the P contributed from the fertilizer and substrate leached between 16 Sept. and 6 Dec. Because leachate were not collected on 7 and 10 Sept., it was unknown how much of the substrate P at 7.8 and 23 mg applied on 10 Sept. were lost through leaching during the initial two irrigations.

The percentage of P distributed in the leachate, shoot, or substrate were calculated as follows:

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

Where A represents leachate P, final shoot P, or final substrate P.

Results and Discussion

TISSUE ANALYSIS. The recently matured leaf P concentration at the 0.4 LF was 26% greater than at the 0 LF with 23 $mg \cdot L^{-1}$ P fertigation but was similar among the three LFs with 7.8 $mg \cdot L^{-1}$ P fertigation (Table 1). The P concentrations in the recently matured leaves for all treatments were well above the critical level of 0.15% (Ecke et al., 1990). With 23 $mg \cdot L^{-1}$ P treatment at the two higher LFs, the recently matured leaf P concentration was above the normal range of 0.3% to 0.6% (Ecke et al., 1990). On average, the P concentration in the recently matured leaves with 23 $mg \cdot L^{-1}$ P fertigation was twice that with 7.8 $mg \cdot L^{-1}$ P fertigation. The higher P consumption did not correspond to an increase in shoot dry mass, leaf area, and bract area. The mean shoot dry mass was 19.2 g, leaf area was 1400 cm^2, and bract area was 4210 cm^2. These data suggested a luxury consumption of P in the high P treatment as reported by Ku (1988) and Tsatsui and Aoki (1981).

PHOSPHOROUS LEACHING. About 58% of the total P leached from the unplanted pots occurred during the first 30 d. Thereafter, the leachate P concentration stabilized to 3 $mg \cdot L^{-1}$ (Fig. 1). This is in agreement with Bunt (1974), Marconi and Nelson (1984), and Yeager and Barrett (1984, 1986) who found that superphosphate P rapidly leached from a soilless substrate. This pattern of P leaching from unplanted pots explains the steep decline in leachate P concentrations in both P treatments of planted pots during the initial 30 d (Fig. 2) and is consistent with studies of planted pots that used superphosphate (Havis and Baker, 1985; Whipker and Hammer, 1994; Yelanich and Biernbaum, 1993).

After the initial 30 d, the leachate P concentration with 7.8 $mg \cdot L^{-1}$ P fertigation decreased to about zero and was similar regardless of LFs and N treatment (Fig. 2). With 23 $mg \cdot L^{-1}$ P fertigation, the leachate P concentrations for both LFs were similar in each N treatment. The leachate P concentration in the 23 $mg \cdot L^{-1}$ P treatment with 100% NO_3-N fertigation ranged from 2 to 18 $mg \cdot L^{-1}$ and from 13 to 41 $mg \cdot L^{-1}$ with 60% NO_3-N fertigation. For environmentally sound container production, the P leaching pattern of the 7.8 $mg \cdot L^{-1}$ was more desirable because it minimized P leaching.

More of the total P leached at the higher LF because a larger volume was applied and leached

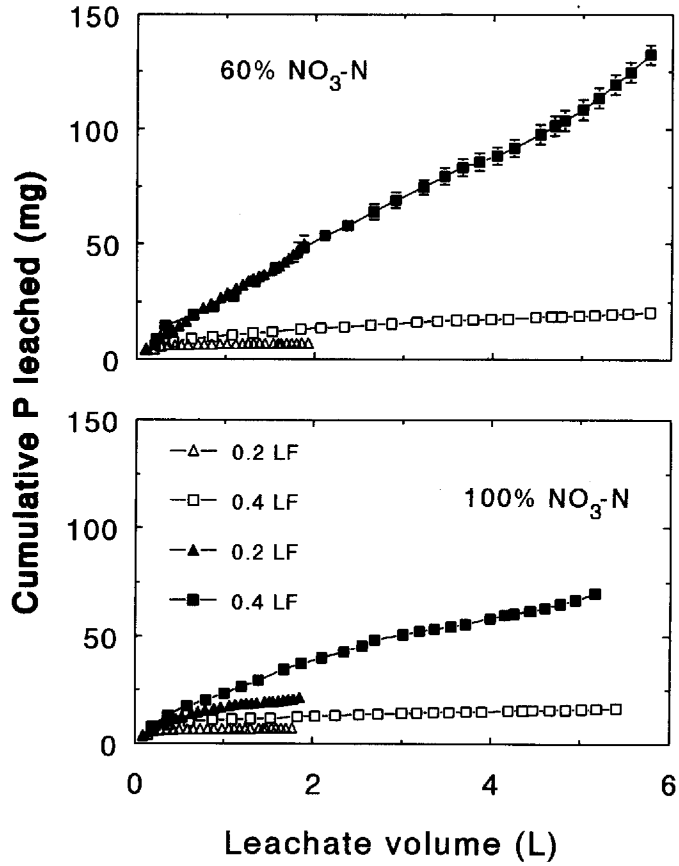

Fig. 3. Cumulative P leached for P at 7.8 $mg \cdot L^{-1}$ (open symbols) and 23 $mg \cdot L^{-1}$ (filled symbols) with (leaching fractions) LFs of 0.2 and 0.4. Each point represents a mean ± SE, n = 5. If not shown, the error bar lies within the symbol.

Table 2. Overall fertigation P applied, leachate P, shoot P, substrate P, and P recovered at harvest.[z]

NO_3-N (%)	P ($mg \cdot L^{-1}$)	LF	Fertigation P (mg)	Leachate P (mg)	Shoot P (mg)	Substrate P (mg)	P recovered (%)[y]
60	7.8	0	50.8	0	67.8	35.3	75.1
		0.2	71.8	7.2	79.4	31.0	74.3
		0.4	102	20.6	100.5	35.9	83.2
60	23	0	174	0	98.2	78.7	68.0
		0.2	228	50.1	116.2	76.8	77.4
		0.4	360	132	149.7	67.5	78.7
100	7.8	0	51.0	0	52.4	46.3	71.7
		0.2	70.3	7.4	59.0	48.9	73.5
		0.4	101	16.7	76.6	46.4	74.4
100	23	0	156	0	88.8	74.5	67.5
		0.2	229	21.6	115.7	95.9	74.1
		0.4	308	69.9	128.3	107.2	77.3
$LSD_{0.05}$							
N[w]			11	2.3	6.0	4.3	2.1
P			11	2.3	6.0	4.3	2.1
LF			14	2.9	7.3	5.2	2.5
N × P			16	3.3	8.4	6.0	2.9
N × LF			19	4.1	10	7.4	3.6
P × LF			19	4.1	10	7.4	3.6
N × P × L			27	5.7	15	10	5.1

[z]Data represents mean, n = 5.
[y]Percent recovery = (leachate P + shoot P + substrate P) ÷ [fertigation P + initial substrate P (79 mg) + initial plant P (7.5 mg)].
[w]Nitrogen fertigation (N), P rate (P), and leaching fraction (LF).

(Fig. 3). The total P leached for both N treatments with 7.8 mg·L^{-1} P fertigation was similar in each LF (Table 2). However, with the 23 mg·L^{-1} P fertigation, the total P leached from the 60% NO_3-N treatment was 2.1-times more than the P leached from the 100% NO_3-N treatment. In contrast to the 7.8 mg·L^{-1} P fertigation, the total P leached was 7-times more with 23 mg·L^{-1} P and 60% NO_3-N treatment and was at most 4-times greater with 23 mg·L^{-1} and 100% NO_3-N treatment.

The difference in the amount of P leached were related to the N sources and substrate pH. In most plant species, root uptake of 100% NO_3-N resulted in release of hydroxyl ions that would raise the rhizosphere pH (Mattis and Hershey, 1992). Conversely, root uptake of NH_4-N releases hydrogen ions that would lower the rhizosphere pH. Also, acidification of the substrate occurred due to nitrification of ammonium fertilizer (Bunt, 1988). The initial leachate pH for both N treatments was 5.5. Over the 90 d, the leachate pH gradually decreased with 60% NO_3-N fertigation and gradually increased with 100% NO_3-N fertigation (Fig. 4). At harvest, the substrate pH was 5.2 with 60% NO_3-N and 7.2 with 100% NO_3-N (data not shown).

Soilless substrates have negligible amounts of Al^{3+} and Fe^{3+} (Bunt 1988). The possibility of applied P forming insoluble compounds of Al^{3+} and Fe^{3+} at low pH was minimal, so the applied P was available for uptake or leaching. This was beneficial with the low P treatment because more P was available for root uptake and prevented any growth restriction (Table 1). However, the high P treatment was more than sufficient for normal growth, and the increase in P solubility resulted in a greater P loss through leaching

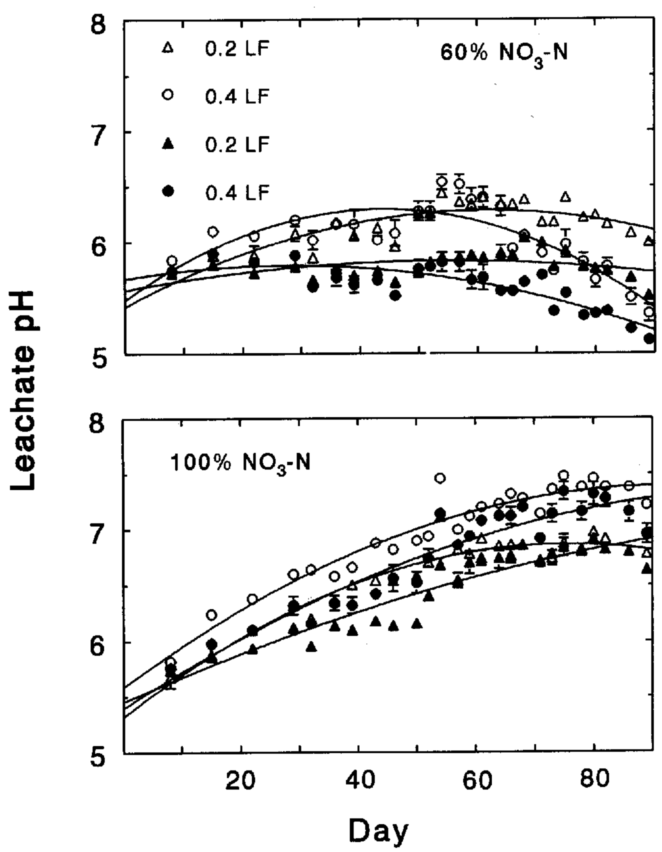

Fig. 4. Leachate pH for 7.8 mg·L^{-1} P (open symbols) and 23 mg·L^{-1} P (closed symbols) with (leaching fractions) LFs of 0.2 and 0.4. Each point represents a mean ± SE, n = 5. If not shown, the error bar lies within the symbol.

(Fig. 2, Table 2). In this study, fertigation solution contained Ca^{2+} at 200 mg·L^{-1}. The chances of phosphate ions forming an insoluble Ca^{2+} precipitate was high with a soil solution pH near 7 (Tisdale et al., 1985) and was indicated by the substrate P data (Table 2). The substrate P contents with 100% NO_3-N fertigation were usually greater than with 60% NO_3-N fertigation. This was beneficial with the high P treatment because it reduced P leaching (Fig. 2), which explained the lower leachate P with 100% NO_3-N than with 60% NO_3-N. However, this could be a problem at the low P fertigation because less P was available for uptake and could result in P deficiency. This problem did not occur in our study as the P concentration in the recently matured leaves with the low P and 100% NO_3-N treatment was in the normal range (Table 1).

Phosphorous distribution and recovery. The percentage of recovered P in the shoot was similar within each of the P concentration and N treatments regardless of LF (Fig. 5). The shoot P content increased with increasing LF. This increase is related to salinity stress, thus the plants were larger at the 0.4 LF than at the 0 LF (data not shown). With the 7.8 mg·L^{-1} P fertigation, 51% to 66% of the recovered P was distributed in the shoot and only at most 13% was distributed in the leachate, which shows the plants were efficient in P uptake. Although a greater amount of P was distributed in the leachate at the 0.4 LF, it was not >38% of the total P recovered.

The P recovery at harvest ranged from 68% to 83% (Table 2). For unaccounted P, 1) most of the roots were discarded during substrate sampling; however, some small broken pieces were left in the substrate. Since substrate P was determined with a digestion procedure, it probably accounted for a small fraction of the root P. The estimated root P content ranged from 17 to 50 mg P based on a concurrent poinsettia solution culture study with a shoot : root ratio of 3:1 (unpublished data). 2) The leachate was not collected on the second irrigation, thus it is unknown how much of the 7.8 and 23 mg of applied P was leached. 3) The superphosphate P leached from unplanted pot between 16 Sept. to 6 Dec. was 31 mg, but the P leached on the initial two irrigations were not determined. Five new unplanted pots were leached with the same volume of tap water (2.8 L) as the previous unplanted pots. All the leachates were collected, and the P leaching pattern was the same as the previous unplanted pots. The total P leached was 54 mg (SE ±0.94). Thus, we estimated about 23 mg (54 to 31 mg) of the superphosphate could have leached during the initial two irrigations.

Conclusions

Leachate P concentrations were sometimes >40 mg·L^{-1}, which is higher than agricultural land P runoff of ≤1 mg·L^{-1} (Sharpely et al., 1994). Using spacing at seven plants per square meter, the estimated P leached was 50 mg·m^{-2} at the 0.2 LF and 490 mg·m^{-2} at the 0.4 LF for a 13-week crop cycle. Based on our P leaching data, the total P leached with a 0.4 LF would be at most 1960 mg·m^{-2} annually, which is equivalent to the annual P requirement of bermuda grass [*Cynodon dactylon* (L.) Pers.], sorghum [*Sorghum bicolor* (L.) Moench], or wheat (*Triticum aestivum* L.) (Sharpley et al., 1994).

There was a luxury consumption of P with 23 mg·L^{-1} P fertigation, but not with 7.8 mg·L^{-1} P fertigation. With 7.8 mg·L^{-1} P fertigation, the plants were extremely efficient in P uptake and there was minimal leaching. The P fertigation rates used in our study were lower than the P at 36 to 117 mg·L^{-1} found in some typical complete fertilizers with the recommended N fertigation rate of 250 mg·L^{-1} (Hartley, 1992). In typical potted poinsettia production, N fertilizers include both N forms, suggesting more P will be leached

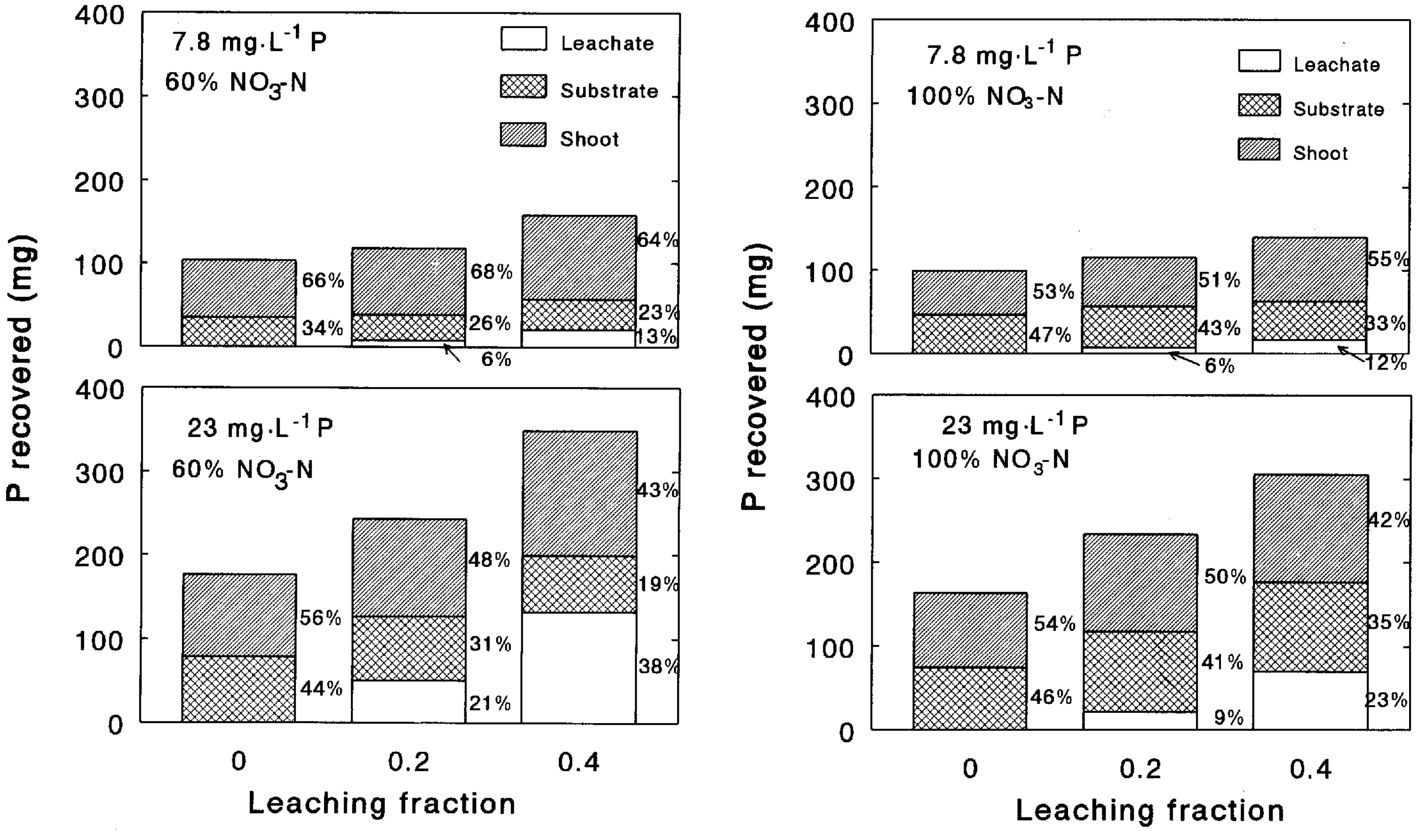

Fig. 5. Percentage P partitioned in the leachate, shoot, and substrate for potted poinsettia for both P rates with 60% NO_3-N fertigation and 100% NO_3-N fertigation. The percentage P partitioned was calculated based on the total P recovered at harvest.

because NH_4-N uptake increases P solubility via a decrease in rhizosphere pH.

Premium and good marketable quality poinsettias were produced with P at 7.8 mg·L^{-1} via fertigation and 57 mg soluble superphosphate with 60% NO_3-N at all three LFs. The superphosphate P was rapidly leached from the planted substrate. Thus, it may be possible to reduce or eliminate superphosphate application to the substrate if P fertigation is used or vice versa. As demonstrated by Yelanich and Biernbaum (1993) with poinsettias that did not receive P fertigation until 13 weeks after their study began, the shoot dry mass was similar with LFs of 0 to 0.55. Alternatively, the P concentration in the commonly available commercial soluble fertilizers could be reduced. For example, a 20N–10P_2O_5–20K_2O fertilizer at 200 mg·L^{-1} N fertigation provides P at 44 mg·L^{-1}. Under the conditions of our study, a 20N–2P_2O_5–20K_2O fertilizer would be more desirable for efficient P fertilization. This new fertilizer analysis would reduce P application by 80%.

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