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Temperature and Phosphorus Source Affect Phosphorus Retention by a Pine Bark-based Container Medium

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Abstract. **These studies were conducted to determine the effect of 1) temperature on P leaching from a soilless medium amended with various P fertilizers, 2) water application volume on P leaching, and 3) various fertilizers on P leaching during production and growth of marigolds (*Tagetes erecta* L. 'Hero Flame'). Increasing temperature linearly decreased leaching fraction; however, total P leached from the single (SSP) or triple (TSP) superphosphate-amended medium did not differ regardless of temperature. Despite a smaller leaching fraction at higher temperatures and no change in the total P leached, P was probably leached more readily at higher temperatures. More P was leached from the medium amended with uncoated monoammonium phosphate (UCP) than from the medium containing polymer-coated monoammonium phosphate (CTP) at all temperatures, and more P was leached from UCP-amended medium at lower temperatures than at higher temperatures. More P was leached from TSP- than from SSP-amended medium and from UCP- than from CTP-amended medium regardless of the water volume applied, but leachate P content increased linearly as water application volume increased for all fertilizers tested. Plant dry weights did not differ regardless of P source. Leachate electrical conductivity (EC) was lower with TSP than with SSP. Leachate EC was also lower with CTP than with UCP. A higher percentage of P from controlled release fertilizer was taken up by plants rather than being leached from the medium compared to P from uncoated fertilizers.**

The application of phosphate fertilizers is seldom necessary in the field unless soil tests determine that P is below a critical value (Davidson et al., 1994). In field soils, P moves very slowly from the point of placement (Tisdale and Nelson, 1975); therefore, P remains available for plant use as long as it is placed in the plant root zone, and is not chemically bound by other elements in an unavailable form. Based on this premise, some container nurseries incorporate single (SSP) or triple (TSP) superphosphate in addition to controlled release fertilizer into the growing medium at the time of mixing to assure adequate P availability. While components included in container media vary widely, many container growing media do not contain any field soil. Spinks and Pritchett (1956) demonstrated that water-soluble P readily moves through a soilless medium profile if the pH is below 6.0; however, in media with pH above 6.0, P movement is restricted. They recommended a topdress with water-soluble P when media pH was below 6.0, and incorporation of P into the media with a pH higher than 6.0.

Other research has shown that P leaches readily from superphosphate-amended soilless container media (Yeager and Barrett, 1984, 1986; Yeager and Wright, 1982;). In these studies as much as 80% of the P was leached from 2 milled pine bark : 1 Canadian sphagnum peat : 1 builders' sand (by volume) (Yeager and Barrett, 1984, 1986). The addition of aluminum significantly decreased P leaching (Williams and Nelson, 1996; Yeager and Barrett, 1986). Spinks and Pritchett (1956), however, showed that small amounts of Fe or aluminum increase P solubility in media with a lower pH. We are not aware of any studies that have evaluated the effect of temperature on P leaching from soilless media.

The objectives of these studies were to determine the effect of 1) temperature on P leaching from a soilless medium amended with various P fertilizers, 2) water application volume on P leaching, and 3) various fertilizers on P leaching during production and growth of marigolds.

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Materials and Methods

In all experiments, ≈757 mg of P was applied to each 1-L pot (15 cm in diameter, 15 cm deep) receiving a P fertilizer, regardless of fertilizer type.

Temperature and superphosphate leaching (Expt. 1). A medium consisting of 3 composted pine bark : 1 peat : 1 sand (by volume) was amended with (kg•m^{-3}) 2.4 gypsum, 2.4 dolomitic limestone, 0.9 Micromax (Grace-Sierra, Milpitas, Calif.) and 3.1 SSP (0N–8.6P–0K), or 1.4 TSP (0N–19.8P–0K), or no P fertilizer. About 97% of SSP particles and 100% of TSP particles were between 2 and 3 mm in diameter. The plastic pots were filled with 1 kg of medium. Five pots from each treatment were maintained at one of four temperatures: 1) in a cooler at 6 ± 1 °C, 2) in a laboratory at 23 ± 2 °C, 3) in a heated chamber at 37 ± 2 °C, or 4) in a heated chamber at 47 ± 2 °C. Heated chambers 56 cm wide × 152 cm long × 20 cm deep were constructed with a 56-cm-wide × 152-cm-long rubber heating mat (Progro; A.H. Hummert, St. Louis) as the base, and 2.5-cm-thick foam insulation (Thermasheath, Rmax, Dallas) for walls and 1.25-cm-thick foam insulation for the top. Pots were elevated above the heating mat by placing 2.5-cm-wide strips of 2.5-cm-thick foam insulation ≈7.5 cm apart on the mats, then setting the pots on the foam strips. Temperatures were monitored daily with soil thermometers (Taylor Bi-therm, A.H. Hummert). Distilled, deionized water (250 mL) was applied daily to the medium in each pot for 14 d. All leachate from each pot was collected and measured daily, then electrical conductivity (EC) measured with a solubridge (Beckman Instruments, Cedar Grove, N.J.), pH measured with a pH meter (Cole Parmer, Chicago), and P determined colorimetrically (Olsen and Sommers, 1982).

Temperature and monoammonium phosphate leaching (Expt. 2). Experiment 1 was repeated, except the P fertilizers incorporated into the medium included UCP (11N–22.4P–0K) or CTP (10N–20.6P–0K; Pursell Industries, Sylacauga, Ala.). About 74% of UCP and 98% of CTP particles were between 2 and 3 mm in diameter. Pots were maintained at 3 ± 1 °C, 24 ± 1 °C, 37 ± 2 °C, or 48 ± 4 °C. All other procedures were the same as in Expt. 1.

Water volume and superphosphate leaching (Expt. 3). Pots and medium were prepared as described in Expt. 1 and maintained at 49 ± 4 °C. Distilled, deionized water was applied in 250-, 350-, or 450-mL increments daily for 26 d. Leachate volume and P content from each pot were determined daily.

Water volume and monoammonium phosphate leaching (Expt. 4). Medium was prepared as described in Expt. 2 and treated as described in Expt. 3.

Plant growth (Expt. 5). This experiment was conducted in a corrugated polycarbonate-covered greenhouse with average minima/maxima of 21/24 °C and a maximum photosynthetic photon flux of 1296 μmol•m^{-2}•s^{-1}. The medium was prepared as described in Expts. 1 and 2, except polymer-coated K_2SO_4 (0N–0P–37K, Pursell Industries) was added to each medium at 3.8 kg•m^{-3}. Three marigold plants per pot were planted into half of the pots from each fertilizer treatment on 13 Oct. 1994. Nitrogen from NH_4NO_3 at 701 mg•L^{-1} was added to the medium without P and with SSP or TSP, at 647 mg•L^{-1} to that with UCP, and at

631 mg•L^{-1} to medium amended with CTP. The N was applied in 250-mL portions each of the 2 days before planting and twice weekly thereafter. All pots received 250 mL of clear tap water every sixth irrigation to reduce soluble salt accumulation. All treatments received N at 10.4 kg•m^{-3} over the course of the experiment, which reflects typical outdoor plant production. The runoff from each pot was collected after every irrigation, measured, and analyzed for P concentration. Plants were harvested on 1 Dec. 1994 and dry mass of shoots and roots was determined. The shoots were then ground to pass through a 1-mm screen, 1 g from each sample was dry ashed, and P determined colorimetrically (Olsen and Summers, 1982).

Statistics. A split-plot design with five replications was used in Expts. 1 and 2. Temperature was the main plot and fertilizer was the subplot. A completely randomized design was used in Expts. 3, 4, and 5. Experiments 3 and 4 had four replications while Expt. 5 had 10. Analysis of variance procedures were performed on all data and LSD values were calculated for significant fertilizer main effects in Expt. 2 and significant main effects and interactions in Expt. 5. Trend analysis was used to determine linear and quadratic relationships among temperatures in Expts. 1 and 2 and among water application volumes in Expts. 3 and 4. Regression models were determined for leachate volume and P released in Expt. 5 (Tablecurve; Jandel Scientific, Corte Madera, Calif.).

Results

Temperature and superphosphate leaching (Expt. 1). No significant fertilizer × temperature interactions existed for leaching fraction, leachate P content, or initial or final pH or EC (Table 1). Leaching fraction was unaffected by fertilizer type, and the amount of P leached was similar regardless of whether SSP or TSP was the P source. About 47% of the P in the SSP-amended medium and 50% of the P from the TSP-amended medium was released within 14 days. All fertilizer treatments differed in initial and final pH and EC. The leachate from medium amended with SSP had the lowest pH and highest EC, while the leachate from the medium with no P had the highest pH and lowest EC.

Increasing temperature linearly decreased the leaching fraction and did not affect the amount of P leached. Initial pH decreased linearly as temperature increased; however, no relationship existed between final pH and temperature. There was a significant curvilinear relationship between temperature and initial and final EC.

Temperature and monoammonium phosphate leaching (Expt. 2). No significant fertilizer × temperature interactions existed for leaching fraction (Table 2). Fertilizer significantly affected leaching fraction with the CTP-amended medium having a higher leaching fraction than the UCP-amended medium. As temperature increased, leaching fraction decreased curvilinearly. The fertilizer × temperature interaction was significant for amount of P leached. As temperature increased, the total amount of P leached from the CPT-amended medium increased linearly. In contrast, as temperature increased, P content of leachate from UCP-amended substrate decreased linearly.

Initially, there was a significant fertilizer × temperature interaction for pH and EC. Leachate pH from CTP- and UCP-amended substrate decreased linearly as temperature increased (Table 2). Leachate EC from CTP- and UCP-amended medium increased linearly as temperature increased. By the end of the study, there were no significant fertilizer × temperature interactions for leachate pH or EC; however, a curvilinear relationship existed between pH and temperature regardless of fertilizer treatment. As temperature increased, EC increased linearly at the end of the study.

Water volume and superphosphate leaching (Expt. 3). There were no fertilizer × water application interactions for leaching fraction or P leached (Table 3). Type of fertilizer did not affect leaching fraction, but leachate P content from the TSP-amended medium was greater than for the SSP-amended medium. As the amount of water applied increased, the leaching fraction and amount of P leached increased linearly.

There were no fertilizer × water applica-

Table 1. Characteristics of medium amended with no P (NOP), single (SSP), or triple (TSP) superphosphate and maintained at various temperatures for 13 days; Expt. 1.

Variable	Leaching fraction	P leached (mg)	Initial pH	Initial EC (dS•m^{-1})	Final pH	Final EC (dS•m^{-1})
Fertilizer						
NOP	0.52	---[z]	4.3	2.46	4.7	1.40
SSP	0.51	340	3.8	3.15	4.1	2.52
TSP	0.51	363	4.0	2.92	4.4	1.66
Temperature (°C)						
6	0.68	253	4.2	2.11	4.5	1.29
23	0.54	254	4.1	2.75	4.5	1.79
37	0.46	350	4.0	3.12	4.5	2.16
47	0.38	249	4.0	3.39	4.3	2.20
Significance						
Fertilizer (F)						
$LSD_{0.05}$	NS	NS	0.10	0.16	0.15	0.14
Temperature (T)						
Linear (L)	***	NS	*	***	NS	***
T-Quadratic	NS	NS	NS	*	NS	**
F × T	NS	NS	NS	NS	NS	NS

[z]The amount of P leached from NOP (14.4 mg) was subtracted from the amounts leached from treatments with fertilizer to determine differences between SSP and TSP in P released.
NS, *, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001 respectively.

Table 2. Characteristics of medium amended with no P (NOP), coated (CTP), or uncoated (UCP) monoammonium phosphate and maintained at various temperatures; Expt. 2.

Temp (°C)	Fertilizer	Leaching fraction	P leached (mg)	Initial pH	Initial EC (dS•m^{-1})	Final pH	Final EC (dS•m^{-1})
3	NOP	0.82	---[z]	4.80	1.96	5.10	0.74
	CTP	0.82	27	4.76	1.27	4.95	0.76
	UCP	0.80	468	4.59	2.58	4.89	1.08
24	NOP	0.65	---	4.83	2.32	5.26	1.25
	CTP	0.64	58	4.68	2.42	4.98	1.41
	UCP	0.61	390	4.46	3.32	4.93	1.52
37	NOP	0.60	---	4.78	2.86	5.33	1.33
	CTP	0.57	148	4.56	3.26	5.02	1.65
	UCP	0.54	265	4.35	5.26	5.03	1.48
48	NOP	0.49	---	4.67	3.36	4.98	1.60
	CTP	0.50	211	4.48	3.79	4.83	1.94
	UCP	0.47	290	4.25	5.90	4.84	1.82
Significance							
Fertilizer (F)		**	***	***	***	***	**
Temperature (T)- Linear (L)		***	NS	***	***	NS	***
T-Quadratic (Q)		**	*	**	NS	***	NS
F × T		NS	***	***	***	NS	NS
NOP × TL		---	---	**	***	---	---
NOP × TQ		---	---	**	NS	---	---
CTP × TL		---	***	***	***	---	---
CTP × TQ		---	NS	NS	NS	---	---
UCP × TL		---	***	***	***	---	---
UCP × TQ		---	NS	NS	NS	---	---

[z]The amount of P leached from the no P treatment (6.7 mg) was subtracted from the amounts leached from treatments with fertilizer to determine differences between CTP and UCP in P release.
NS, *, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

Table 3. Leaching fraction and P leached from medium amended with single (SSP) or triple (TSP) superphosphate and receiving various amounts of water daily; Expt. 3.

Treatment	Leaching fraction	P (mg)
Fertilizer		
SSP	0.66	553
TSP	0.67	611
Water (mL/application)		
250	0.57	517
350	0.68	581
450	0.74	648
Significance		
Fertilizer (F)	NS	***
Water (W)-Linear	***	***
W-Quadratic	NS	NS
F × W	NS	NS

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

Table 4. Characteristics of leachate from medium amended with single (SSP) or triple (TSP) superphosphate and receiving various amounts water daily; Expt. 3.

Fertilizer	Water applied (mL)	Initial pH	Initial EC ($dS \cdot m^{-1}$)	Final pH	Final EC ($dS \cdot m^{-1}$)
SSP	250	4.09	3.32	4.51	0.66
	350	4.13	2.94	4.61	0.38
	450	4.13	2.90	4.71	0.18
TSP	250	4.04	2.78	4.74	0.24
	350	4.17	2.44	4.89	0.12
	450	4.18	2.14	4.78	0.06
Significance					
Fertilizer (F)		NS	***	**	***
Water (W)-linear (L)		**	***	NS	***
W-Quadratic (Q)		NS	NS	NS	NS
F × W		NS	NS	NS	***
SSP × WL		---	---	---	***
SSP × WQ		---	---	---	NS
TSP × WL		---	---	---	***
TSP × WQ		---	---	---	***

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

Table 5. Characteristics of leachate from medium amended with coated (CTP) or uncoated (UCP) monoammonium phosphate and receiving various amounts of water daily; Expt. 4.

Treatment	Leaching fraction	P (mg)	Initial pH	Initial EC ($dS \cdot m^{-1}$)	Final pH	Final EC ($dS \cdot m^{-1}$)
Fertilizer						
CTP	0.59	378	4.66	2.88	5.06	0.33
UCP	0.58	605	4.55	3.81	5.26	0.25
Water (mL/application)						
250	0.50	429	4.62	4.09	5.02	0.43
350	0.59	508	4.60	3.32	5.22	0.25
450	0.65	538	4.60	2.62	5.25	0.18
Significance						
Fertilizer (F)	NS	***	**	***	NS	***
Water (W)-Linear	NS	NS	NS	***	NS	***
W-Quadratic	NS	NS	NS	NS	NS	**
F × W	NS	NS	NS	NS	NS	NS

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

Table 6. Leaching fraction and P leached from container medium with or without marigolds and amended with various P fertilizers; Expt. 5.

Plant	Fertilizer	Leaching fraction	P (mg)
Yes	NOP[z]	0.15	---[y]
	SSP	0.13	256
	TSP	0.09	280
	CTP	0.05	78
	UCP	0.11	360
No	NOP	0.27	---
	SSP	0.26	293
	TSP	0.30	409
	CTP	0.22	193
	UCP	0.29	407
Significance ($LSD_{0.05}$)			
Plant (P)		0.03	37
Fertilizer (F)		0.02	26
P × F		0.05	75

[z]NOP = no P fertilizer, SSP = single superphosphate, TSP = triple superphosphate, CTP = coated monoammonium phosphate, UCP = uncoated monoammonium phosphate.
[y]The amount of P leached from the no P treatment (9.75 mg) was subtracted from the amounts leached from treatments with fertilizer to determine differences between SSP, TSP, CTP, and UCP in P release.

tion interactions for initial or final pH or EC (Table 4). Initial leachate pH from the substrate amended with SSP did not differ from that of substrate amended with TSP; however, by the end of the study, leachate pH from the TSP-amended medium was significantly greater than for SSP-amended medium. A positive linear relationship existed between initial pH and volume of water applied, and a negative linear relationship between initial EC and water application volumes occurred. On SSP- and TSP-amended medium, there was a linear and curvilinear decrease, respectively, in EC as water application volume increased.

Water volume and monoammonium phosphate leaching (Expt. 4). No fertilizer × water application interactions existed for leaching fraction, leachate P content, or initial or final pH or EC (Table 5). Fertilizer type did not affect leaching fraction, but leachate from the UCP-amended medium contained more P (80% of P applied) than leachate from the CTP-amended medium (50% of P applied). Initial pH and final EC of leachate were higher and initial EC was lower for substrate amended with CTP compared to substrate amended with UCP.

Leaching fraction and leachate P content were not affected by volume of water applied (Table 5). Initial EC decreased linearly and final EC decreased curvilinearly as the water application volumes increased.

Plant growth (Expt. 5). There was a significant plant × fertilizer interaction for leaching fraction and leachate P content (Table 6). The presence of plants decreased leaching fraction and leachate P content in all fertilizer treatments. The most P was in leachate from substrate amended with TSP and UCP without plants, but in the presence of plants, leachate from UCP-amended substrate contained the most P. Plants receiving no P had a lower shoot dry mass than plants with any fertilizer (Table 7). Root dry mass of plants receiving CTP was larger than that of plants receiving UCP. The root : shoot ratio of plants in medium without P was higher and the root : shoot ratio of plants in the UCP medium was lower than those of plants in media amended with SSP, TSP, or CTP. The percentage of P in the plants did not differ among those that received fertilizer, but plants receiving no fertilizer had a lower percentage of P (Table 7).

Phosphorus leaching from media amended with any fertilizer except CTP increased rapidly with increasing runoff, such that after a small volume of water had been leached, a plateau in P leaching had been reached (Fig. 1). However, P release from the coated fertilizer was more uniform and a plateau had not been reached by the end of the experiment.

Discussion

Regardless of fertilizer source in Expt. 1, the amount of P leached remained the same despite a decreased leaching fraction as temperatures increased. Therefore, the concentration of P was higher in the smaller leaching fractions obtained at higher temperatures. This result suggests that P was more readily leached at the higher temperatures when SSP or TSP

Table 7. Characteristics of marigolds grown in container medium with various P fertilizers. Expt. 5.

Fertilizer	Dry mass (g) Shoot	Dry mass (g) Root	R : S ratio	Tissue P (%)
NOP[z]	1.5 c[y]	0.23 ab	0.15 a	0.11 b
SSP	3.8 b	0.27 ab	0.07 b	0.69 a
TSP	4.4 ab	0.27 ab	0.06 b	0.65 a
CTP	4.5 a	0.30 a	0.07 b	0.67
UCP	3.9 b	0.19 b	0.05 c	0.66 a

[z]NOP = no P fertilizer, SSP = single superphosphate, TSP = triple superphosphate, CTP = coated monoammonium phosphate, UCP = uncoated monoammonium phosphate.
[y]Mean separation by Student–Newman–Keul's procedure at $P \leq 0.05$.

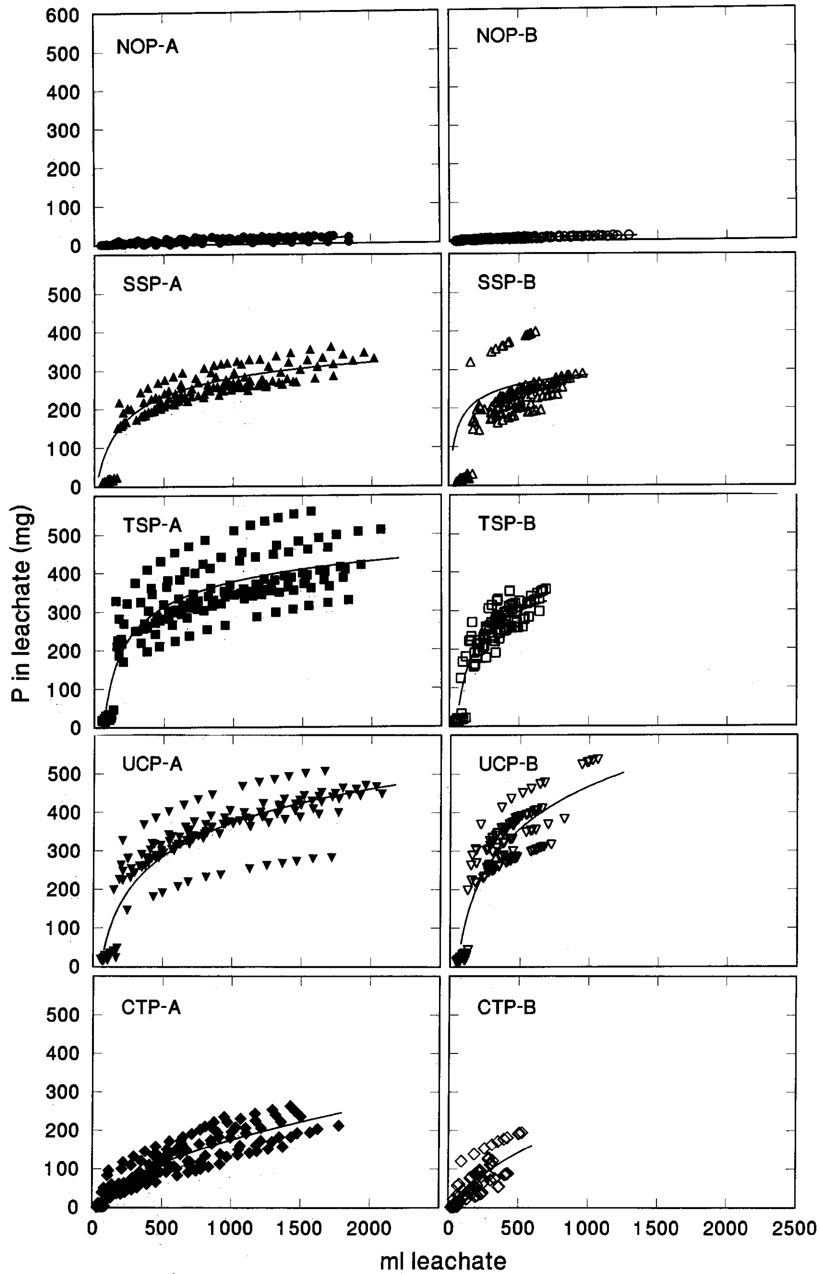

Fig. 1. Amount of P in leachate from medium amended with no P (NOP), single superphosphate (SSP), triple superphosphate (TSP), uncoated monoammonium phosphate (UCP), or coated monoammonium phosphate (CTP) without (**A**) or with (**B**) plants. The regression equations were as follows: NOP $y = a + b(\ln x)^2$, without plants a = –6.60 and b = 0.37 ($r^2 = 0.57$), with plants a = –4.23 and b = 0.28 ($r^2 = 0.80$); SSP $\ln y = a + b/x^{0.5}$, without plants a = 6.09 and b = –14.41 ($r^2 = 0.80$), with plants a = 5.87 and b = –6.89 ($r^2 = 0.31$); TSP $y = a + b/\ln x$, without plants a = 956.21 and b = –4001.82 ($r^2 = 0.77$), with plants a = 809.14 and b = –3180.78 ($r^2 = 0.86$); UCP $y = a + b\ln x$, without plants a = –507.77 and b = 127.53 ($r^2 = 0.81$), with plants a = –623.15 and b = 157.98 ($r^2 = 0.81$); CTP $y = a + bx^{0.5}$, without plants a = –34.52 and b = 6.63 ($r^2 = 0.81$), with plants a = –54.75 and b = 8.79 ($r^2 = 0.64$); Expt. 5.

was the fertilizer source. Similarly, P was leached more readily at the higher temperatures in Expt. 2 when CTP was the fertilizer source. The CTP had a polymer coating designed to reduce fertilizer release so that nutrients were more available for plant use throughout the growing season. Controlled release fertilizers with a permeable outer covering release at higher rates when temperatures increase (Maynard and Lorenz, 1979; Pursell Industries, 1992), as was apparent in this study. In contrast, no conclusions can be drawn from these studies as to the effect of temperature on P leaching from UCP. Monoammonium phosphate is highly soluble in water and temperature may have a limited influence on its leaching characteristics under typical plant production conditions.

In Expt. 3, TSP appeared to be more soluble than SSP, and thus more easily leached. Similarly, in Expt. 4, UCP was more soluble than CTP and therefore more easily leached. In both of these studies, a decrease in EC with higher water application volumes may be attributed to reduced soluble salts when the medium leaching fractions were high.

The decreased leaching fraction in the presence of plants (Expt. 5, Table 6) can be attributed to plant uptake of water during transpiration. The smaller amount of P leached from medium containing plants compared to medium without plants may be partially attributed to plant uptake of P; however, the reduction in the leachate released from the medium with plants compared to medium without plants probably accounts for more of the difference in P release between the plus and minus plant treatments.

While some sources recommend the incorporation of superphosphate into soilless growing media (Biamonte et al., 1993; Nelson, 1991), results of our studies agree with those of Yeager and Barrett (1984 and 1986) in which P from SSP was quickly released from the medium (45% in 13 days) (Table 1). While the added P may be present for plant use during the first few days of the growing season, the P is quickly lost through leaching and superphosphates may be unnecessary and wasted. Phosphorus leaching appears to be an especially important process, considering that most plant production takes place using media with a pH at or below 6.0. The use of controlled release fertilizers such as CTP slows P release and can retain available P for plant use over a longer time period (Fig. 1). In addition, a higher percentage of P was retained by the plants instead of being leached from the media when CTP fertilizer was used compared to all uncoated fertilizers tested.

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