Using Precharged Zeolite as a Source of Potassium and Phosphate in a Soilless Container Medium during Potted Chrysanthemum Production

Kimberly A. Williams¹ and Paul V. Nelson²

Department of Horticultural Science, North Carolina State University, Raleigh, NC 27695-7609

ADDITIONAL INDEX WORDS. *Chrysanthemum × morifolium*, *Dendranthema × grandiflorum*, soilless substrate, adsorption, clinoptilolite, slow-release fertilizer, cation exchange capacity

ABSTRACT. Most soilless container root media have limited ability to retain nutrients. Zeolites are minerals of substantial cation exchange capacity that can be precharged with K, and possibly PO₄, and used as a component of soilless media as a slow-release nutrient source. A zeolite clinoptilolite (Cp) was charged with K and PO₄ at two concentrations and combined at 20% of the mix with sphagnum peat (60%) and perlite (20%) to evaluate its use as the sole source of these nutrients during production of *Dendranthema × grandiflorum* (Ramat.) Kitamura 'Sunny Mandalay.' Phosphate, K, Na, and pH were determined on unaltered bulk root medium solutions collected over the course of production, and foliar analyses were determined on tissue collected at the middle and end of the crop. All leachate was collected and analyzed to allow for the creation of K and PO₄ budgets. Plants that relied on precharged Cp at the low and high rates to meet their K needs and received a N/P-K fertilizer had similar dry mass and tissue K concentrations as the control plants that received a complete fertilizer. The use of precharged Cp at the low rate reduced K losses through leaching to 23% of the amount lost from control plants receiving water-soluble fertilizer (WSF). Plants that relied on precharged Cp for their PO₄ had a lower dry mass and tissue P levels than those of the complete control treatment. However, PO₄ concentrations in the root medium solution were above acceptable levels during the first month of production and should be considered when developing a fertilizer application strategy using Cp precharged with PO₄.

Most soilless container root media have limited nutrient retention capacities. Materials with potential as a soilless mix component to improve nutrient buffering capacity are zeolites. Zeolites are crystalline, hydrated aluminosilicates of alkali and alkaline-earth metals with an open, honeycomb-like framework of three-dimensional channels or pores of different sizes that run in several directions throughout the crystal (Ming and Mumpton, 1989). These cavities usually contain loosely held water molecules and freely exchangeable charge-balancing cations, principally K⁺, Na⁺, Ca²⁺, and Mg²⁺. Selectivity for sorption varies among zeolites.

Zeolite cation exchange capacity, which generally ranges between 100 and 300 meq/100 g (Barbarick and Pirela, 1984), and their ability to buffer the concentrations of some cations in nutrient solution have resulted in their study for many horticultural uses (Allen and Ming, 1995) including potted chrysanthemum production (Hershey et al., 1980), creeping bentgrass establishment (Nus and Brauen, 1991), and as a chief component of synthetic soils to be used for food production at a lunar base (Ming, 1989). When Hershey et al. (1980) grew potted chrysanthemums with the sole K source being that which naturally occurred in a source of the zeolite clinoptilolite (Cp), growth equivalent to plants receiving K from a periodically applied nutrient solution was achieved. Zeo-

lites may also adversely affect plant growth if they release high levels of Na or compete with plant roots by absorbing nutrients from the medium solution. If zeolites were precharged, or loaded, with a cation such as K before incorporation into a soilless medium, cation scavenging by the zeolite might be reduced or eliminated because sites of cation sorption would already be saturated with nutritional cations. Furthermore, precharging would exchange much of the potentially harmful Na retained in some natural zeolites with K, Ca, Mg, or even NH₄, depending on the composition of the charging solution.

Zeolites may also be able to sorb PO₄ anions along broken edges of the crystalline structure where hydrated oxides are exposed if PO₄ is introduced during the charging process. Precharged zeolites may serve as a type of slow-release fertilizer, releasing nutrients according to plant demand, with the added ability to buffer medium solution cation concentrations.

The objectives of this study included 1) evaluating the effectiveness of precharged Cp to meet PO₄ and K requirements for potted chrysanthemum; 2) establishing K and PO₄ release curves for precharged Cp; and 3) creating budgets for K and PO₄ use provided by precharged Cp during production of potted chrysanthemum.

Materials and Methods

TREATMENT MATERIAL. The zeolite used was 8 × 20 mesh Cp, mined in Bowie, Ariz. (GSA Resources, Inc., Cortaro, Ariz.). Physical characteristics are reported in Table 1. Amounts of the exchangeable cations K, Na, Ca, and Mg present in the Cp before sorption were determined by extraction with NH₄OAC (Knudsen et al., 1982), and P levels were determined using 0.05 N HCl and 0.025 N H₂SO₄ (Olsen and Sommers, 1982) (Table 1).

GREENHOUSE EXPERIMENT. There were nine treatments. Three treatments were controls and included N/P/K (complete control, treatment 1), N/P-K (-P control, treatment 2), or N/P-K (-K control, treatment 3) fertilizer; Cp was not applied in these treat-

Received for publication 9 Sept. 1996. Accepted for publication 3 Apr. 1997. This research was funded in part by the North Carolina Agricultural Research Service (NCARS) and by a grant from Sun Gro Horticulture, Inc. Use of trade names in this publication does not imply endorsement by the NCARS of products named nor criticism of similar ones not mentioned. Appreciation is extended to Yoder Brothers, Inc., for providing chrysanthemum cuttings. We thank William H. Swallow for his expert statistical guidance. From a thesis submitted by K.A.W. in partial fulfillment of the requirements for the PhD degree. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

¹Graduate assistant. Currently assistant professor, Dept. of Horticulture, Forestry, and Recreation Resources, 2021 Throckmorton Hall, Kansas State Univ., Manhattan, KS 66506-5506.

²Professor.

Table 1. Bulk density, physical characteristics, exchangeable cations, and P extracted from clinoptilolite (Cp) before charging with K and PO₄ from KH₂PO₄.

Pore diam ^z (Å)	Bulk density (g·cm ⁻³)	Cation exchange capacity ^z (meq·g ⁻¹)	SiO ₂ to Al ₂ O ₃ ratio ^z	K	Na	Ca	Mg	P
				(meq·g ⁻¹)				(µg·cm ⁻³)
4.0	0.88	1.65	6.3 : 1	0.18	0.24	0.55	0.03	2.1

^zReported by GSA Resources, Inc., Cortaro, Ariz.

ments. The remaining six treatments contained precharged Cp in a 2 × 3 factorial treatment arrangement consisting of 2 KH₂PO₄ charge rates (high and low) and 3 water-soluble fertilizer (WSF) programs (N/P/K where precharged Cp was the sole source of PO₄ and K; N/P/K where PO₄ was supplied by precharged Cp; and N/P/K where K was supplied by precharged Cp).

A preliminary study was conducted in the laboratory to create K and PO₄ sorption isotherms for Cp following the procedures of Fox and Kamprath (1970). Concentrations of K and PO₄ in the salt solution used to charge Cp were based on this data (not shown). The low rate of charge with KH₂PO₄ was P at 2250 µg·mL⁻¹ (K at 2838 µg·mL⁻¹), which was estimated to result in an equilibrium PO₄ concentration of P at >1 µg·mL⁻¹ in the root medium solution. The high rate was K at 5000 µg·mL⁻¹ (P at 3965 µg·mL⁻¹), which was estimated to result in an equilibrium K concentration of about 125 µg·mL⁻¹ in the root medium solution. Cp was charged with K and PO₄ by measuring 1 solid volume : 6 charging solution volume in Erlenmeyer flasks. Flasks were placed on a circular motion shaker (100 rpm) for 10 days at 23 °C. After the equilibration period, a sample of supernatant was collected for K and PO₄ analysis and drained. Next, the Cp was desorbed by adding 0.01 M CaCl₂ (1 solid : 6 solution volume) and agitated for 6 h on the shaker. The supernatant was sampled and the excess was discarded. This step was repeated. Lastly, the precharged Cp was dried at 70 °C. Potassium and PO₄ that disappeared from the charging solution were considered to be sorbed by the Cp, and K and PO₄ that were released during the desorption steps were considered in the budget calculations.

The control plants were grown in a mixture of 70 low-humified sphagnum peat : 30 coarse perlite (v/v) (Krum, Silbrico Co., Hodgkins, Ill.). Precharged Cp was incorporated into the medium to make up 20% of the volume, resulting in a treatment medium of 20 Cp : 60 peat : 20 perlite. The initial pH of the control mix was 5.0 compared to 5.6 for the Cp mix. The physical properties of the control and treatment mixes were determined on four replications of fallow pots of each by using the tube method of Niedziela and Nelson (1992). The bulk density (g·cm⁻³), air-filled porosity (% by volume), and container capacity (% by volume) were 0.20, 13.3, and 74.8 for the control mix and 0.38, 5.8, and 66.6 for the Cp mix, respectively.

Rooted cuttings of potted chrysanthemum 'Sunny Mandalay' (Yoder Brothers, Inc., Barberton, Ohio) were planted on 17 June 1994, one cutting per 10-cm standard round, green, plastic pot. The medium volume was 500 cm³ and the depth was 10 cm. Root medium was amended with the following materials and rates per cubic meter: 6 kg dolomitic limestone, 0.9 kg gypsum, and 3.3 kg Esmigran micronutrient mix (Scotts-Sierra Horticultural Products, Marysville, Ohio). Pots were spaced 0.2 × 0.028 m apart. Greenhouse night and day temperatures were set at 17 and 25 °C, respectively. Plants received 2 weeks of natural long days followed by 8 weeks of short days (covered with black cloth from about 1700 to 0800 HR) and were pinched 1 week after planting to leave nine nodes. Lateral buds were removed 5.5 weeks after pinching.

Plants received N at 200 µg·mL⁻¹ at each watering. The N/P/K (complete) fertilizer consisted of 4.5 mM KNO₃, 1.5 mM NH₄H₂PO₄, and 4.5 mM NH₄NO₃; the N/P/K fertilizer consisted of 4.5 mM KNO₃, 4.5 mM NH₄NO₃, and 0.75 mM (NH₄)₂SO₄; the N/P/K fertilizer consisted of 1.5 mM NH₄H₂PO₄, 4.5 mM NH₄NO₃, and 2.25 mM Ca(NO₃)₂; and the N/P/K fertilizer consisted of 6 mM NH₄NO₃ and 1.5 mM Ca(NO₃)₂. All fertilizers contained an NH₄-N : NO₃-N ratio of 2:3; ions that varied in concentration among the fertilizers were Ca and SO₄.

Plants were watered when the mass of pots in an experimental unit declined by 25% to 35% of container capacity due to water loss. Pots were weighed once or twice per day. Each treatment was watered separately. A measured volume of fertilizer solution was applied at each watering to result in a controlled leaching fraction of 0.2 and leachate volume was measured each time. To collect the leachate, pots were placed over 600-mL glass beakers before WSF application. After the pots were allowed to drain completely, leachate was collected in plastic milk jugs, to which phenylmercuriacetate was added to prevent microbial growth, and stored in a 5 °C cooler.

Unaltered media solution was sampled by vacuum removal. Fertilizer solutions were applied to pots and allowed to equilibrate for 1 h, then pots were sealed in a suction funnel and a vacuum was drawn on the base of the pot. Ten milliliters of solution was collected from each of the two pots within an experimental unit and combined. Solutions were collected on days 1 (first day after planting), 5, 8, 15, 22, 29, 43, 57, and 66. Media solution samples were analyzed for PO₄-P using a UV/VIS spectrophotometer (Perkin-Elmer, Norwalk, Conn.) following the procedures of Chapman and Pratt (1961) for concentrations >10 µg·mL⁻¹ or Murphy and Riley (1962) for concentrations <10 µg·mL⁻¹; K and Na were determined by atomic absorption spectroscopy; and pH was measured on a combined pH and temperature meter (Extech Instruments Corp., Waltham, Mass.).

Plant height, width, and quality ratings were recorded weekly. Height was measured from the rim of the pot to the top of the foliage or flower canopy and width was the average of two measurements taken at right angles to each other. Plant quality ratings were assigned subjectively after considering plant volume, form, foliage color, and number and size of flowers on a scale of 1 to 10, with 10 representing quality meeting commercial standards (Hamrick, 1989). Fresh and dry mass (dried for a minimum of 48 h at 70 °C) of the total above-ground plant shoots was recorded at end of the crop.

Tissue samples consisted of the youngest, fully expanded leaves at mid-crop and total above-ground shoots at end of the crop. Plant tissue was washed for 30 s in 0.2 N HCl and rinsed for 30 s in distilled water. Dried tissue was ground in a stainless-steel Wiley mill to a particle size ≤1 mm (20-mesh screen). Tissue used for P, K, Ca, Mg, S, Fe, Mn, Zn, and Cu analyses was dry-ashed at 500 °C, dehydrated in HCl, and dissolved in 0.5 N HCl. Tissue from end of the crop harvest used for S and B analysis was ashed in the presence of Mg(NO₃)₂ and ethanol at 450 °C and dissolved in 0.5 N HCl. Total N was determined using a micro-Kjeldahl procedure

Fig. 1. Mineral nutrient concentrations in the medium solution during the greenhouse experiment of root media treated with precharged clinoptilolite (Cp) and water-soluble fertilizer (WSF) regimes. To simplify graphs, results from all treatments are not always shown. (A) $\text{PO}_4\text{-P}$ ($\text{SE} = \text{mean} \pm 1.7$), (B) K ($\text{SE} = \text{mean} \pm 2.9$), (C) Na ($\text{SE} = \text{mean} \pm 1.1$), (D) pH ($\text{SE} = \text{mean} \pm 0.1$); (■) treatment 1, N/P/K WSF (complete control); (□) treatment 2, N/P/K (–P control), (box with x) treatment 3, N/P/–K, (–K control), (Δ) treatment 4, high Cp with N/–P/–K WSF, (▲) treatment 5, high Cp with N/–P/K WSF, (◆) treatment 6, high Cp with N/P/–K WSF, (○) treatment 7, low Cp with N/–P/–K WSF, (●) treatment 8, low Cp with N/P/K WSF, (◇) treatment 9, low Cp with N/P/–K WSF.

solution was adequate for optimal chrysanthemum growth in field culture. This concentration was sustained in the medium solution of all –P WSF plus Cp (treatments 5 and 8) in this experiment through day 43 of the cropping cycle, although plant growth began to differ between treatments before this time (data not shown). Plant growth data indicated that plants that relied on precharged Cp to meet their PO_4 needs (treatments 4, 5, 7, and 8) did not produce

after pretreatment with salicylic acid to aid in the reduction of nitrate (Eastin, 1978). Analysis of K, Ca, Mg, Fe, Mn, Zn, and Cu was conducted using atomic absorption spectroscopy. Phosphorus was determined by the previously mentioned colorimetric methods of P analysis. Sulfur was determined by a turbidimetric procedure in which BaSO_4 was suspended with polyvinyl pyrrolidone (A.H. Hunter, personal communication), and colorimetric analyses were performed for B (Grinstead and Snider, 1967), both using a UV/VIS spectrophotometer.

Treatments were arranged in a randomized complete block with 3 blocks and 2 pots per experimental unit for a total of 54 pots. Data were subjected to analysis of variance (PROC ANOVA, SAS Inst., Cary, N.C.), and least significant differences were calculated as appropriate within the factorial treatment structure for comparison of treatment means.

Results and Discussion

Concentrations of $\text{PO}_4\text{-P}$ release from precharged Cp were adequate for optimal plant growth for the first 4 weeks of production (Fig. 1A), after which PO_4 declined to possibly inadequate levels. Nishimoto et al. (1975) es-

Table 2. Plant growth characteristics for whole above-ground shoots at end of the crop (day 67) from plants grown with precharged clinoptilolite (Cp) comprising 20% of the medium and controls.

Treatment	Ht (cm)	Width (cm)	Fresh mass (g)	Dry mass (g)	Rating
Controls, no Cp					
1 Complete WSF ^a (N/P/K)	22.3	38.5	144.7	16.1	10.0
2 –P WSF (N/–P/K)	14.7	17.2	13.7	3.3	2.0
3 –K WSF (N/P/–K)	11.3	28.3	18.2	2.8	1.0
LSD $\alpha = 0.05^y$	2.0	3.1	12.7	2.1	0.6
Precharged Cp, high rate					
4 –P and –K WSF (N/–P/–K)	20.4	30.9	83.0	12.0	7.3
5 –P WSF (N/–P/K)	20.1	33.0	93.0	12.6	7.7
6 –K WSF (N/P/–K)	22.6	37.1	143.3	14.4	10.0
Precharged Cp, low rate					
7 –P and –K WSF (N/–P/–K)	21.4	30.7	76.0	10.2	8.0
8 –P WSF (N/–P/K)	21.1	32.0	85.3	11.6	7.7
9 –K WSF (N/P/–K)	22.2	36.0	143.1	16.2	10.0
LSD $\alpha = 0.05$	NS ^x	2.3 ^x	10.2 ^x	2.4 ^y	0.6 ^x
	NS ^w	NS ^w	NS ^w		NS ^w

^aWSF = water-soluble fertilizer.

^yLSD used only to compare controls with Cp treatments.

^zLSD used for comparing Cp treatments at all WSF levels of a given rate (high vs. low); WSF by rate interaction is not significant.

^wLSD used for comparing Cp treatments at both rates of a given WSF level; WSF by rate interaction is not significant.

^vLSD used for comparing WSF at a given rate and rate at a given WSF level; WSF by rate interaction is significant.

growth equivalent to the complete control (Table 2). On day 39, height and ratings of plants grown with -P WSF plus Cp (treatments 4, 5, 7, and 8) were similar to the complete control, but width fell short (data not shown). Tissue P concentrations (Table 3) for plants grown with -P WSF plus Cp (treatments 4, 5, 7, and 8) met the standard minimum critical tissue concentration at mid-crop (day 36) of 0.25% (Jones et al., 1991), but fell short of the 0.23% standard at end of the crop (Table 3). This provided more evidence that PO₄ requirement of the plants was met by the precharged Cp for about the first month of the cropping cycle, but then became inadequate. In general, the rate of charge, high versus low, did not result in significant differences in plant growth or tissue P concentrations, and PO₄ release late in the crop was insufficient at both rates (Tables 2 and 3). However, PO₄ release from the precharged Cp during the first month of the cropping cycle should be considered when developing a fertilization program for plants grown with precharged zeolites.

Plants that received K only from precharged Cp at both rates of charge and PO₄ in WSF (treatments 6 and 9) resulted in growth at end of the crop which was not different from the complete control

(Table 2). Tissue K concentrations in all plants that derived K only from precharged Cp (treatments 4, 6, 7, and 9) were higher than the complete control (treatment 1) at mid-crop. At end of the crop, a higher K tissue concentration was measured in plants grown with precharged Cp at the high rate (treatment 6) compared to the complete control. At the low rate of charge (treatment 9) and at both rates of charge for plants receiving the N/-P/-K WSF program (treatments 4 and 7), K tissue concentration was not significantly different than the complete control (Table 2). Thus, the tissue analysis data provided supporting evidence that K was released in sufficient quantity from precharged Cp at both rates of charge to result in optimal plant growth without any additional application.

Warncke and Krauskopf (1983) reported 60 µg·mL⁻¹ as the critical minimum K concentration in saturated medium extract (SME) solutions from soilless greenhouse media. The K concentrations in the root medium solutions measured in this study were below 60 µg·mL⁻¹, except for the first 15 d for plants grown with K only from precharged Cp at the high rate (treatments 4 and 6) (Fig. 1B). Based on plant growth and tissue K concentration

Table 3. Mineral content (dry mass basis) of the youngest fully expanded leaves collected at midcrop (day 36) and of whole above-ground plant tissue at end of the crop (day 67) from plants grown with precharged clinoptilolite (Cp) comprising 20% of the medium and controls.

Treatment	Mineral (%)				
	N	P	K	Ca	Mg
Midcrop					
Controls, No Cp					
1 Complete WSF ^z (N/P/K)	4.94	0.64	3.88	0.91	0.56
2 -P WSF (N/-P/K)	3.29	0.10	3.93	0.47	0.27
3 -K WSF (N/P/-K)	6.25	0.87	0.61	1.49	1.08
LSD a = 0.05 ^y	0.43	0.05	0.32	0.08	0.04
Precharged Cp, high rate					
4 -P and -K WSF (N/-P/-K)	4.76	0.29	5.65	0.73	0.29
5 -P WSF (N/-P/K)	4.83	0.28	5.60	0.68	0.30
6 -K WSF (N/P/-K)	4.79	0.62	5.64	0.84	0.32
Precharged Cp, low rate					
7 -P and -K WSF (N/-P/-K)	4.79	0.26	5.40	0.73	0.28
8 -P WSF (N/-P/K)	4.70	0.27	5.64	0.71	0.27
9 -K WSF (N/P/-K)	4.67	0.61	5.32	0.88	0.33
LSD a = 0.05	NS ^x	0.03 ^x	NS ^x	0.05 ^x	0.02 ^y
	NS ^w	NS ^w	NS ^w	NS ^w	
End crop					
Controls, no Cp					
1 Complete WSF (N/P/K)	3.95	0.79	3.79	0.89	0.53
2 -P WSF (N/-P/K)	2.91	0.09	3.44	0.63	0.33
3 -K (N/P/-K)	5.67	1.01	0.48	1.52	1.10
LSD a = 0.05 ^y	0.33	0.06	0.34	0.06	0.05
Precharged Cp, high rate					
4 -P and -K WSF (N/-P/-K)	2.74	0.13	3.86	0.76	0.27
5 -P WSF (N/-P/K)	2.84	0.15	4.41	0.76	0.33
6 -K WSF (N/P/-K)	3.56	0.75	4.78	0.96	0.34
Precharged Cp, low rate					
7 -P and -K WSF (N/-P/-K)	2.62	0.12	3.79	0.84	0.31
8 -P WSF (N/-P/K)	2.70	0.13	4.26	0.79	0.31
9 -K WSF (N/P/-K)	3.51	0.77	4.07	1.06	0.40
LSD a = 0.05	0.25 ^x	0.04 ^x	0.29 ^x	0.04 ^x	0.03 ^y
	NS ^w	NS ^w	0.24 ^w	0.03 ^w	

^zWSF = water-soluble fertilizer.

^yLSD used only to compare controls with Cp treatments.

^xLSD used for comparing Cp treatments at all WSF levels of a given rate (high vs. low); WSF by rate interaction is not significant.

^wLSD used for comparing Cp treatments at both rates of a given WSF level; WSF by rate interaction is not significant.

^vLSD used for comparing WSF at a given rate and rate at a given WSF level; WSF by rate interaction is significant.

results, K levels $<60 \mu\text{g}\cdot\text{mL}^{-1}$ were sufficient. When K in the root medium solution is continually sustained by an equilibrium mechanism, lower concentrations are adequate compared to a system of periodic application, as is the case with WSF regimes.

Plants in both treatments that relied on the high rate of precharged Cp to meet their K needs (treatments 4 and 6) had the same amount of K in each pot; however, late in the cropping cycle, plants that were grown with the N/P/K WSF fertilizer (treatment 4) resulted in higher medium solution K levels than plants grown with the N/P/K fertilizer (treatment 6) (Fig. 1B). It could be speculated that this resulted not because precharged Cp released less K in the latter case but because, during the 1-h equilibration period between fertilization and root medium solution sampling, the larger plants grown with the N/P/K fertilizer removed a larger amount of K from the medium solution through uptake. A parallel comparison could be made for the plants grown at the low rate of precharged

Cp, N/P/K and N/P/K fertilizers (treatments 7 and 9), with the same resulting observation.

The Na levels recovered in the medium solution were generally higher in all treatments that contained precharged Cp than in the complete control (Fig. 1C). Highest Na concentrations were measured in the medium of plants receiving the N/P/K fertilizer (treatments 5 and 8). This may have occurred because K applied in the liquid fertilizer displaced Na on the cation exchange sites of the precharged Cp. Sodium release in media of plants receiving the N/P/K fertilizer (treatments 6 and 9) was not apparently damaging to plant growth as it was similar to that of the complete control (Table 2). However, it is unclear whether the additional Na released in media of plants fertilized with the N/P/K fertilizer (treatments 5 and 8) affected growth. Sodium tissue analysis was not conducted.

The pH of media with precharged Cp and N/P/K WSF (treat-

Table 4. Average proportion of added P and K, which was recovered in the leachate, plants, or estimated to remain in pots, from treatments grown with precharged clinoptilolite (Cp) comprising 20% of the medium and controls.

Treatment	Total P or K ²	Leachate (%)	Plants		Remain in pot ³ (%)
	applied (mg/pot)		Shoots (%)	Roots ^y (%)	
P budgets					
1 Complete WSF ^w , (N/P/K)		36.5	45.0	11.2	7.2
	(281) ^v	(103)	(127)	(31.6)	(20.1)
2 -P WSF, (N/-P/K)	(0)		(2.8)	(0.7)	
LSD a = 0.05 ^u		7.1	5.7	1.4	10.0
4 High rate, (N/-P/-K)		13.0	16.8	4.2	66.1
	(95.1)	(12.3)	(16.0)	(4.0)	(62.8)
5 High rate, (N/-P/K)		10.4	20.1	5.0	64.5
	(95.1)	(9.9)	(19.1)	(4.8)	(61.3)
7 Low rate, (N/-P/-K)		18.2	26.1	6.5	49.2
	(48.2)	(8.8)	(12.6)	(3.1)	(23.7)
8 Low rate, (N/-P/K)		11.9	31.9	8.0	48.1
	(48.2)	(5.8)	(15.4)	(3.9)	(23.2)
LSD a = 0.05		2.5 ^{ts}	NS ^t	1.1 ^{ts}	NS ^t
			4.6 ^s		6.7 ^s
K budgets					
1 Complete WSF, (N/P/K)		17.5	57.3	14.4	10.8
	(1060)	(186)	(608)	(152)	(115)
3 -K WSF, (N/P/-K)	(0)		(13.7)	(3.4)	
LSD a = 0.05 ^u		3.9	4.9	1.2	3.9
4 High rate, (N/-P/-K)		3.6	14.8	3.7	77.9
	(3136)	(112)	(464)	(116)	(2442)
6 High rate, (N/P/-K)		3.7	20.4	5.1	70.8
	(3136)	(115)	(640)	(160)	(2220)
7 Low rate, (N/-P/-K)		2.5	17.7	4.4	75.5
	(2197)	(54)	(388)	(97)	(1658)
9 Low rate, (N/P/-K)		2.0	30.1	7.5	60.5
	(2197)	(43)	(661)	(165)	(1329)
LSD a = 0.05		NS ^t	3.7 ^r	1.0 ^r	3.8 ^r
		0.6 ^s			

²Nutrient applied as liquid fertilizer (complete control) or sorbed on clinoptilolite (Cp) (all other treatments).

³Liberal estimation of P in roots was calculated by assuming that root mass was 25% of the shoot dry mass and P concentration in roots was the same as in shoot.

^xCalculated by subtracting P recovered in plants and leachate from the total applied.

^wWSF = water-soluble fertilizer.

^vNumbers in parentheses are total mg P or K.

^uLSD used only to compare controls with Cp treatments.

^tLSD used for comparing Cp treatments at both WSF levels of a given rate (high vs. low); WSF by rate interaction is not significant.

^sLSD used for comparing Cp treatments at both rates of a given WSF level; WSF by rate interaction is not significant.

^rLSD used for comparing WSF at a given rate and rate at a given WSF level; fertilizer by rate interaction is significant.

ments 6 and 9) generally fell within an acceptable range for soilless media of 5.1 to 5.6 (Fig. 1D). In comparing the pH in the complete control medium (treatment 1) with that resulting from precharged Cp and N/P/-K WSF (treatments 6 and 9), it was interesting that the precharged Cp had little effect on the pH. The tissue concentrations of the plants that relied on precharged Cp to meet their K needs and received N/P/-K WSF (treatments 6 and 9) met minimum critical concentrations at mid-crop and end of the crop, except that Ca levels were slightly lower than the minimum critical values reported by Jones et al. (1991). However, the Ca levels for the complete control are also lower than the standard level of 1.0% at mid-crop and 1.2% at end of the crop (Table 3). Micronutrient analyses showed no clear trends among treatments, and the presence of Cp did not apparently alter availability or uptake of these elements (data not shown).

The P budget data (Table 4) further documented the inadequacy of charged Cp to serve as the sole source of PO_4 . If one assumes that 0.25% P is the minimum required tissue concentration in the chrysanthemum shoot, then plants in the best treatment in this study that had a shoot dry mass of 16.2 g required 40.5 mg of PO_4 -P per plant. This does not take into account the root requirement that is roughly estimated at 25% of the shoot requirement, thus raising the total P requirement to 49 mg/plant. Not all PO_4 -P is released from Cp during crop production, however. At the end of the cropping cycle, the average percentages of Cp-supplied PO_4 remaining in the root medium in the high rate (treatments 4 and 5) and the low rate (treatments 7 and 8) were 65% and 49%, respectively (Table 4). This means that P levels applied per pot would need to be 81 and 71 mg for the high and low charged Cp treatments, respectively, to meet plant requirements even before efficiency of plant uptake is considered. Therefore, the total amount of P applied per pot at both rates by the precharged Cp can be questioned as insufficient. Also of importance in the P budget data (Table 4) is the lower percentage of PO_4 leached from the Cp treatments (4, 5, 7, and 8) than from the control treatment where PO_4 is applied solely as WSF (treatment 1), i.e., 10% to 18% versus 37%, respectively.

The K budgets demonstrated that K lost in the leachate was greatly reduced when precharged Cp was the sole source of K (treatments 4, 6, 7, and 9) compared to the complete control (treatment 1) receiving WSF (Table 4), even though more total K was added to pots with precharged Cp (2197 to 3136 mg/pot; treatments 4, 6, 7, and 9) than applied as WSF (1060 mg/pot; treatment 1). High and low charge levels with N/P/-K fertilizer resulted in optimal chrysanthemum growth, so 2.0% lost K in leachate (43 mg) is all that must be tolerated. Precharged Cp at the low charge level (treatment 9) reduced K losses through leaching to 23% of the amount lost from control plants receiving complete WSF (treatment 1). A substantial percentage (61% to 78%) of the applied K from precharged Cp remained in the pots at the end of the experiment and would presumably be released and available for plant uptake later (Table 4). This would be advantageous for 1) ratoon crops such as cut flowers and vegetables; 2) long-term crops including foliage, azalea, and nursery crops; 3) the consumer who will maintain the crop indefinitely; and 4) interior landscapes.

Hershey et al. (1980) successfully produced chrysanthemum solely with naturally occurring K in a Cp source. Precharged Cp can also be used as the sole source of K in soilless media to meet the K requirement of chrysanthemum. The capacity for Cp to simultaneously provide PO_4 is limited. However, the initial PO_4

release from this material should not be ignored when designing a crop fertilization program. Future studies should address the use of zeolites for providing other essential cationic nutrients including NH_4 , Ca, and Mg in addition to K. Any additional costs associated with such a zeolite system might be offset by reductions in conventional soluble fertilizer consumption during the cropping cycle and a greatly simplified nutritional program for the grower.

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