# Effect of Pre-plant Phosphate Charge and Leaching on Phosphorus Longevity in Soilless Substrate[1]

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## Abstract

There is little information addressing the impact of quantity of pre-plant phosphate charge in soilless substrate and leaching during production on soluble phosphate longevity when post-plant phosphate is omitted. Two experiments were conducted growing *Petunia* ×*hybrida* 'Primetime White' seedling crops over a 42-d period in a sphagnum peat moss-perlite substrate. Phosphate-phosphorus (P) charge levels of 0.03, 0.06, 0.12, and 0.18 kg·m$^{-3}$ (0.05, 0.10, 0.20 and 0.30 lbs·yd$^{-3}$, respectively) and 0, 20, and 50% leaching were tested. The first experiment was conducted in winter (late November through December) and the second in spring (mid-March through April). The minimum-targeted, soluble-bulk-solution phosphate-P level of 3 mg·L$^{-1}$ (ppm) was achieved for 41 d in the winter with a phosphate-P charge of 0.06 kg·m$^{-3}$ (0.10 lbs·yd$^{-3}$) and 20% leaching. Longevity for this treatment was 4 d less in the spring. At 0% leaching, the soluble-bulk-solution phosphate-P level was above the minimum target level of 3 mg·L$^{-1}$ (ppm) for the entire 42-d period in both seasons. Increasing the leaching from 20 to 50% resulted in a loss of longevity by 4 d in the winter and 6 d in the spring.

**Index words:** soilless media, bedding plants, floriculture, *Petunia* ×*hybrida*, plant nutrition.

**Species used in this study:** petunia (*Petunia* ×*hybrid* var. *multiflora* Vilm.).

## Significance to the Horticulture Industry

It is now common practice to grow ornamental container crops with a marginally low phosphorus stress to achieve compactness, aesthetic quality, and in the case of plants valued for their red or purple color, deeper pigmentation. However, excessive stress must be avoided to prevent irreversible symptoms of chlorosis and necrosis. The choice of pre-plant phosphate fertilizer in the root substrate impacts growth and flowering of longer term crops such as chrysanthemum and geranium. When these plants transition from foliar to flower growth, root uptake of phosphate declines while an increased demand occurs in the flowers. To maintain a marginally low P stress at this stage, there must be an ample supply of P in the foliage, otherwise unacceptable P deficiency symptoms will occur in the foliage due to translocation of P to flowers. Knowledge of the longevity of pre-plant phosphate must be known to design the post-plant fertilization program. This study determined that a pre-plant charge of 0.06 kg·m$^{-3}$ (0.10 lbs·yd$^{-3}$) phosphate-P (equivalent to 1.2 lb·yd$^{-3}$ single superphosphate) with 20% leaching will maintain the necessary substrate solution phosphate-P level of $\geq$ 3 mg·L$^{-1}$ (ppm) for nearly six weeks in the winter. The shift from slower growth in winter to desirable spring growing conditions reduced longevity by only four days. When the application of 20% excess water or fertilizer solution (leaching) at each irrigation was increased to 50%, longevity decreased modestly by four days in winter and six days in spring.

## Introduction

Classic symptoms of P deficiency in plants follow the sequence of shorter internodes, deeper green color, increased root to shoot ratio, red to purple foliar pigmentation, and chlorosis in older leaves followed by necrosis (Gibson et al. 2007, Khandan-Mirkohi and Schenk 2009). Recent fertilization practices for plug seedlings and ornamental crops sold in containers are often designed to achieve the early P deficiency stress symptoms of shorter internodes and deeper green color without advancing to later symptoms of chlorosis and necrosis (Nelson et al. 2012). Commercial benefits from this stress include plant compactness, improved aesthetic quality, and for those plants valued for their red or purple foliage, a more intense color (Henry 2017).

Whipker (2014) reported occurrence of P deficiency symptoms in upper (younger) rather than lower (older) foliage of chrysanthemum [*Dendranthema* ×*grandiflora* (Ramat.) Kitam] during flowering. Hansen and Lynch (1998a, 1998b) found a shift in phosphate sink location from roots and foliage to flowers in chrysanthemum during flowering, along with a decline in root uptake. Henry (2017) confirmed the sink shift for chrysanthemum, ornamental pepper (*Capsicum annuum* L.), geranium (*Pelargonium* ×*hortorum* LH Bailey), and *Alternanthera brasiliana* (L.) Kuntze and reported a simultaneous shift in P source from root uptake to lower foliage during flowering. As flowers and young leaves immediately below flowers developed, P translocation from lower foliage supplied the increased demand in flowers, leaving the

[1]Received for publication May 19, 2017; in revised form July 20, 2017. This research was funded in part by a grant from The Fred C. Gloeckner Foundation, Inc. and the North Carolina Agricultural Research Service (NCARS), Raleigh, NC 27695-7643. Use of trade names in this publication does not imply endorsement by the NCARS of the products named nor criticism of similar ones not mentioned. We gratefully acknowledge Nancy C. Mingis for assistance with substrate and tissue analyses. Appreciation is expressed to Sun Gro Horticulture, Inc. for providing substrate components and Goldsmith Seeds, Inc. for seeds.

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newly forming leaves below the flowers deficient. This demonstrated the need to build a supply of P in foliage during early crop production when a marginally low P stress is desired later in production.

Plug seedling production times can range from two to ten weeks or more with six weeks being common (Dole and Wilkins 2005, Styer and Koranski 1997). Production of ornamental container crops can range from three to four weeks for some bedding plants to twelve or more weeks for crops such as rose and cyclamen (Dole and Wilkins 2005). Soilless substrates are commercially available with or without a pre-plant phosphate charge (Barrett 1992). Pre-plant phosphate-P charge levels commonly used for soilless substrates throughout six European countries, the United States, and Australia range from 0.03 to 0.16 $kg{\cdot}m^{-3}$ (0.05 to 0.27 $lbs{\cdot}yd^{-3}$) (Bunt 1976, Handreck and Black 2002). Since soilless substrates do not typically contain clay materials or other components with high phosphate sorption capacities, a pre-plant phosphate charge will decline rapidly due to leaching (Marconi and Nelson 1984).

The residual duration of pre-plant phosphate is dependent on the magnitude of the pre-plant phosphate charge and other factors such as leaching during crop production and plant phosphate uptake rate. To control phosphate availability within the narrow confines of a marginal deficiency stress, one must decide whether to apply a pre-plant phosphate charge, and if so, what charge level to use. This information is lacking in the literature. In short-term crops, maintenance of a marginally low substrate phosphate level is best served by omitting pre-plant phosphate which allows control of the P stress through the post-plant fertilization program. In longer term crops, pre-plant phosphate can be an advantage for averting excessive P stress early in the crop, leaving control of a marginal P stress later in the crop through post-plant fertilization. However, it is important to know when this source of phosphate runs out for accurate design of the post-plant phosphate program. Objectives of this study were to evaluate the effects of quantity of pre-plant phosphate-P charge and leaching on substrate phosphate-P longevity under poor winter and rapid spring growing conditions.

## Materials and Methods

Two experiments were conducted using *Petunia ×hybrida* var. *multiflora* 'Primetime White'. Substrate was prepared using 75% sphagnum peat moss [$\leq$6 mm particle diameter ($\leq$ 0.24 in)] and 25% perlite [$\leq$3 mm ($\leq$0.12 in)] on a v/v basis amended with 3.0 $kg{\cdot}m^{-3}$ (5.0 $lbs{\cdot}yd^{-3}$) dolomitic limestone, 1.5 $kg{\cdot}m^{-3}$ (2.5 $lbs{\cdot}yd^{-3}$) Esmigran micronutrient mix (The Scotts Miracle-Gro Company, Marysville, OH), and 1.2 $kg{\cdot}m^{-3}$ (2.0 $lbs{\cdot}yd^{-3}$) gypsum. Treatments (Table 1) consisted of two factors: pre-plant phosphate-P charge from monobasic calcium phosphate [$Ca(H_2PO_4)_2.H_20$] and leaching. As indicated in Table 1, the fertilization frequency was adjusted with the leaching treatment. Experiment 1 (Expt. 1) consisted of two parts: The first set of treatments tested the responses of substrate pH, bulk-solution phosphate-P and shoot tissue P concentration to three pre-plant phosphate-P charges. The second set of treatments tested the response of bulk-solution phosphate-P and shoot tissue P concentration to three leaching treatments. Experiment 2 (Expt. 2) also had two parts. The first consisted of two charge levels of pre-plant phosphate-P. The second encompassed three leaching treatments.

**Table 1. Treatments of pre-plant phosphate-phosphorus (P) charge from monobasic calcium phosphate [$Ca(H_2PO_4)_2{\cdot}H_2O$], leaching percentage, and fertilization frequency applied to plants grown in 288-cell plug trays in Expts. 1 and 2.**

| P charge[z] ($kg{\cdot}m^{-3}$) | Leaching (%) | Fertilization frequency[y] |
|---|---|---|
| *Expt. 1 – phosphate charge treatments* | | |
| 0.06 | 20 | Every second day |
| 0.12 | 20 | Every second day |
| 0.18 | 20 | Every second day |
| *Expt. 1 – leaching treatments* | | |
| 0.06 | 0 | Every third day |
| 0.06 | 20 | Every second day |
| 0.06 | 50 | Every day |
| *Expt. 2 – phosphate charge treatments* | | |
| 0.03 | 20 | very second day |
| 0.06 | 20 | Every second day |
| *Expt. 2 – leaching treatments* | | |
| 0.06 | 0 | Every third day |
| 0.06 | 20 | Every second day |
| 0.06 | 50 | Every day |

[z]Pre-plant phosphate-P charges of 0.03, 0.06, 0.12 and 0.18 $kg{\cdot}m^{-3}$ substrate are equivalent to 0.05, 0.10, 0.20 and 0.30 $lbs{\cdot}yd^{-3}$, respectively. Also, 1.0 $lb{\cdot}yd^{-3}$ single superphosphate supplies 0.053 $kg{\cdot}m^{-3}$ P.

[y]Plants were either watered or fertilized every morning for all treatments using the nitrogen (N) and potassium (K) rates described in the text.

Seeds were sown in 288-cell plug trays in Expt. 1 on November 22 and in Expt. 2 on March 15. After sowing, trays were watered to achieve 0, 20 or 50% leaching and placed in a dark germination chamber at 24 C (75 F). Five days later, trays were arranged in a randomized complete block design in a glass greenhouse at latitude 35°N in Raleigh, NC. Day and night temperatures were set at 24 C (75 F) and 18 C (65 F), respectively. Beginning seven days after sowing, trays were fertilized and thereafter either watered or fertilized each morning, as specified in Table 1. The nitrogen (N) concentrations were 50, 75, and 90 $mg{\cdot}L^{-1}$ (ppm) when fertilized every day, every second day, and every third day, respectively, for the entire time in Expt. 1 and for the first 4 weeks in Expt. 2. After the fourth week in Expt. 2, the N concentrations were raised to 75, 125, and 150 $mg{\cdot}L^{-1}$ (ppm), respectively. The fertilizer concentrations were increased due to more rapid growth because of increased solar radiation in April versus December. All fertilizer solutions were formulated with equal levels of N and potassium oxide ($K_2O$), resulting in a 1 N to 0.83 potassium (K) ratio, using reagent-grade potassium nitrate ($KNO_3$) and ammonium nitrate ($NH_4NO_3$) with 35.2% of the N supplied in the ammoniacal form.

*Data collection.* Substrate was analyzed periodically for pH in pre-plant phosphate-P charge treatments in Expt. 1 and soluble phosphate-P in all treatments in both experiments. At each substrate solution sampling, trays were watered or fertilized and 12 shoots from each tray were immediately cut off and discarded in all but the last sample date (42 days after sowing). One hour later, the substrate from the 12 excised plugs was removed from the tray, placed in cheesecloth, and substrate solutions were squeezed from the plugs by hand. The pH was measured using a Model 695 pH/conductivity/TDS/temperature meter (Extech Instruments, Waltham, MA). Colorimetric analyses using a Perkin and Elmer Lambda 3 UV/VIS spectrophotometer (Norwalk, CT) were performed for phosphate-P [concentrations under 10 $mg \cdot L^{-1}$ (ppm) were determined using the technique described by Murphy and Riley (1962) and concentrations above 10 $mg \cdot L^{-1}$ (ppm) were determined using the technique described by Chapman and Pratt (1961)].

On the last sample date, shoots were cut off, rinsed in tap water, washed in 0.2 N HCI for 1 min, rinsed in distilled water, dried at 70 C, weighed, and ground in a stainless-steel Wiley Mill to pass a 1 mm screen (20-mesh). Tissue was then dry-ashed at 500 C, dehydrated in 3 N HCl, and dissolved in 0.5 N HCl. Colorimetric analysis was performed for phosphate-P (Chapman and Pratt 1961) in a UV/VIS spectrophotometer (Perkin and Elmer, Norwalk, CT).

*Experimental design and statistical analysis.* All treatments were arranged in a randomized complete block design and each plug tray was an experimental unit. In Expt. 1 – pre-plant phosphate-P charge treatments, a two-way factorial arrangement of three pre-plant phosphate-P charges and five sample dates with four blocks (60 experimental units in total) was employed for the substrate solution assays. For the shoot tissue analysis performed only at 42 d, there were three pre-plant phosphate-P charges with four blocks (12 experimental units in total). In Expt. 1 – leaching treatments, a two-way factorial arrangement of three leaching treatments and four sample dates with four blocks (48 experimental units in total) was employed for the substrate solution assays. For the shoot tissue P analysis, there were three leaching treatments with four blocks (12 experimental units in total). In Expt. 2 – pre-plant phosphate-P charge treatments, a factorial arrangement of two pre-plant phosphate-P charges and five sample dates with four blocks (40 experimental units) was used for substrate phosphate-P assays. For the shoot tissue P analysis at 42 d, there were two pre-plant phosphate-P charges and four blocks (8 experimental units). In Expt. 2 – leaching treatments, a factorial arrangement of three leaching treatments and five sample dates with four blocks (60 experimental units) was used for substrate phosphate-P assays. For shoot tissue P analysis at 42 d, there were three leaching treatments and four blocks (12 experimental units).

All data were analyzed using analysis of variance by PROC GLM (SAS 9.4, SAS Institute, Cary, NC). In Expt. 1, pH and soluble phosphate-P data values for all treatments were regressed by sample date using the PROC GLM procedure to determine the best-fit linear and quadratic models. Upon inspection, the soluble phosphate-P data in Expt. 2 appeared to require a logarithmic transformation after which a linear trend appeared sufficient. The PROC GLM procedure was used on the log transformed data to determine the best fit linear model for each treatment. The anti-log of the linear equation was then used to plot curves. Terms of each model were tested using F-values and significance level $\alpha = 0.05$. Means and standard errors were calculated for all data in both experiments using PROC MEANS.

## Results and Discussion

*Expt. 1 - Pre-plant phosphate-P charge treatments.* In this set of treatments, where all treatments received 20% leaching, the pre-plant phosphate-P charge by day interaction was significant for the substrate pH and bulk-solution phosphate-P variables. Substrate pH levels rose over time for each treatment as limestone continued to dissolve (Fig. 1A). While there was little difference in substrate pH levels between the 0.06 and 0.12 $kg \cdot m^{-3}$ (0.10 and 0.20 $lbs \cdot yd^{-3}$, respectively) pre-plant phosphate-P charges, levels associated with the 0.18 $kg \cdot m^{-3}$ (0.30 $lbs \cdot yd^{-3}$) charge were lower at each date. This can be explained two ways. In the pH range encountered in this experiment, the two species of phosphate present would be mono-basic $H_2PO_4^-$ and di-basic $HPO_4^{2-}$ with a $pK_a$ of 7.2. Since only the mono-basic species was added, dissociation of protons was anticipated, resulting in greater pH decline with larger additions of phosphate-P. Also, increased phosphate addition in the presence of calcium can drive the reaction toward hydroxyapatite formation with a release of protons as seen in the following reaction (Lindsay 1979):

$$5Ca^{2+} + 3H_2PO4^- + H_2O \rightarrow Ca_5(PO4)_3OH + 7H^+ \quad K^\circ = -14.46$$

Bulk-solution phosphate-P data over 42 d resulting from pre-plant phosphate-P charges of 0.06, 0.12, and 0.18 $kg \cdot m^{-3}$, all at 20% leaching, are presented in Figs. 1B and 1C. On the sowing date, all treatments had higher bulk-solution phosphate-P concentrations than the 3 to 5 $mg \cdot L^{-1}$ (ppm) range reported as acceptable by Warncke and Krauskopf (1983), with concentrations ranging from 100 to 446 $mg \cdot L^{-1}$ (ppm). Bulk-solution levels in these treatments declined with time. At four weeks, levels were still well above adequate. At week six, the pre-plant substrate phosphate-P concentration in the 0.06 $kg \cdot m^{-3}$ treatment was below adequate at 1.5 $mg \cdot L^{-1}$, the 0.12 $kg \cdot m^{-3}$ treatment was adequate at 4.3 $mg \cdot L^{-1}$, and the 0.18 $kg \cdot m^{-3}$ treatment was well above adequate at 16.9 $mg \cdot L^{-1}$. The time required for curves to decline to 3 $mg \cdot L^{-1}$ were 41, >42, and >42 d for pre-plant phosphate-P charges of 0.06, 0.12, and 0.18 $kg \cdot m^{-3}$, respectively.

*Expt. 1 - leaching treatments.* In this experiment where all treatments received a pre-plant phosphate-P charge of 0.06 $kg \cdot m^{-3}$, the leaching treatment by day interaction was significant for bulk-solution phosphate-P. Bulk-solution phosphate-P levels declined over time at all leaching treatments (Fig. 2). Bulk-solution phosphate-P levels were lower with each increase in leaching and over time the three leaching treatment curves for bulk-solution phosphate-P levels converged. Bulk-solution phosphate-P levels remained $\geq$ 3 $mg \cdot L^{-1}$ for >42, 41, and 37 d in the 0, 20, and 50% leaching treatments, respectively.

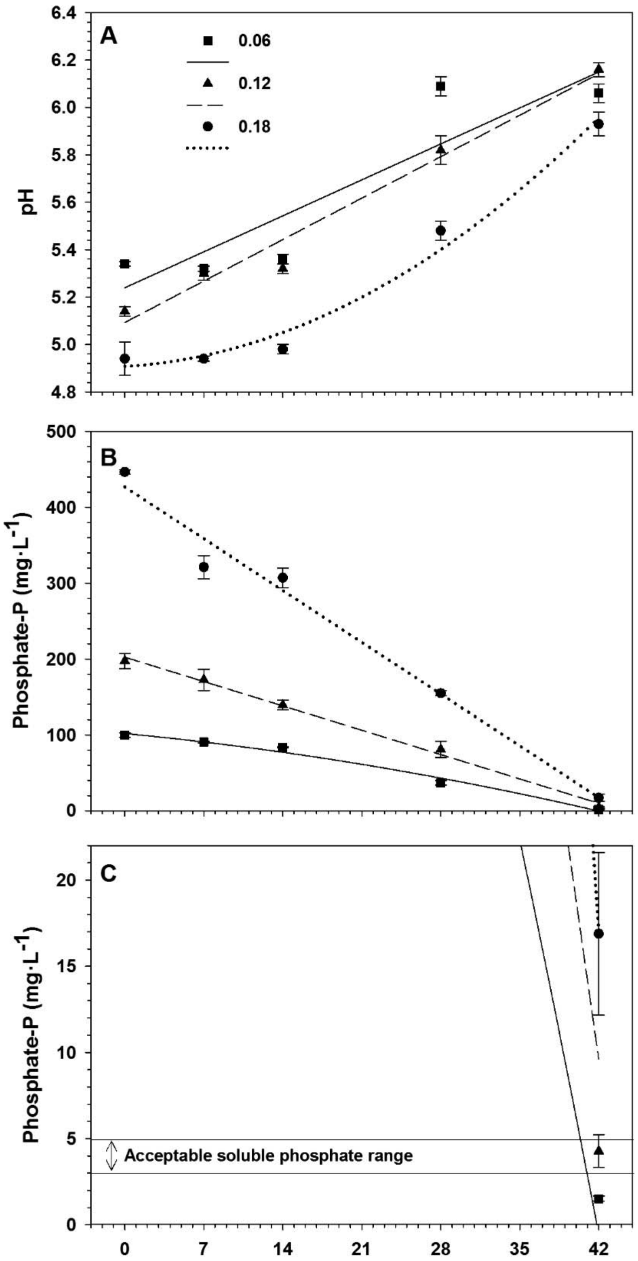


**Fig. 1.** Effects of three pre-plant phosphorus (P) charges (0.06, 0.12, and 0.18 $kg·m^{-3}$ equivalent to 0.10, 0.20 and 0.30 $lbs·yd^{-3}$, respectively) under 20% leaching on the mean A) pH and B) bulk-solution phosphate-P concentration of the soilless substrate from 0 to 42 days after sowing petunia for plants grown in 288-cell plug trays in Expt. 1. Figure 1C is an expansion in the range from 0 to 22 $mg·L^{-1}$ (ppm) phosphate-P of the data shown in Fig. 1B. The acceptable bulk-solution phosphate-P range of 3 to 5 $mg·L^{-1}$ (ppm) presented by Warncke and Krauskopf (1983) is indicated. The regression equations generated from the best fit models were: A) $y_{0.06} = 5.24 + 0.0217x$ ($r^2 = 0.81$), $y_{0.12} = 5.10 + 0.0248x$ ($r^2 = 0.94$), and $y_{0.18} = 4.91 + 0.00295x + 0.000524x^2$ ($r^2 = 0.95$) and B&C) $y_{0.06} = 101.67 - 1.43x - 0.0239x^2$ ($r^2 = 0.98$), $y_{0.12} = 202.20 - 4.58x$ ($r^2 = 0.94$), and $y_{0.18} = 426.89 - 9.76x$ ($r^2 = 0.97$). Vertical bars indicate ± S.E. (n = 4).

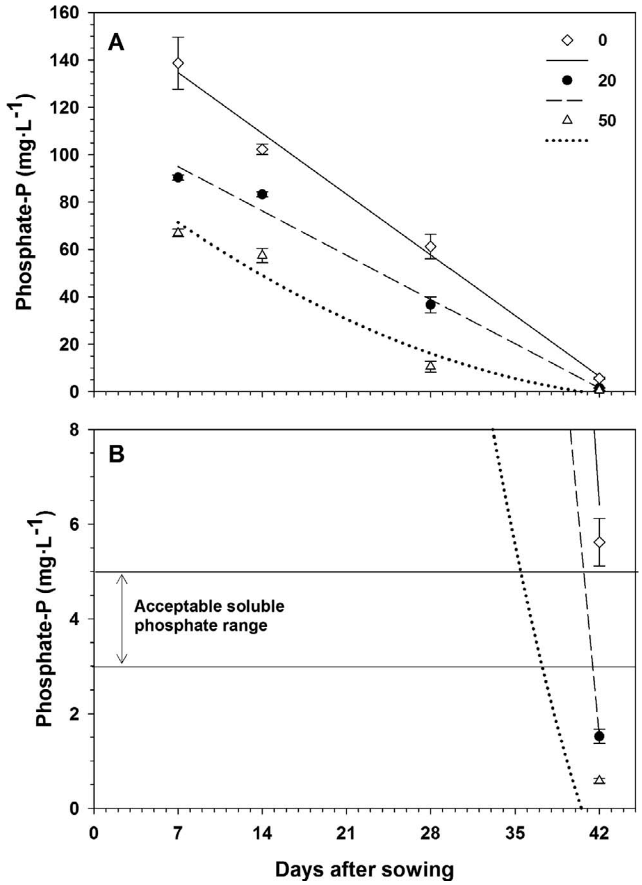


**Fig. 2.** Effects of three leaching treatments (0, 20, and 50%) with a pre-plant phosphorus (P) charge of 0.06 $kg·m^{-3}$ (0.10 $lbs·yd^{-3}$) on the mean bulk-solution phosphate-P concentration of the soilless substrate from 7 to 42 days after sowing petunia for plants grown in 288-cell plug trays in Expt. 1. Figures 2B is an expansion in the range from 0 to 8 $mg·L^{-1}$ (ppm) phosphate-P of data shown in Figs. 2A. The acceptable bulk-solution phosphate-P range of 3 to 5 $mg·L^{-1}$ (ppm) presented by Warncke and Krauskopf (1983) is indicated. The regression equations generated from the best fit models were: $y_0 = 160.36 - 3.66x$ ($r^2 = 0.95$), $y_{20} = 113.72 - 2.67x$ ($r^2 = 0.98$), and $y_{50} = 97.74 - 4.04x + 0.0401x^2$ ($r^2 = 0.95$). Vertical bars indicate ± S.E. (n = 4).

*Expt. 2 – pre-plant phosphate-P charge treatments.* The main effects of pre-plant phosphate-P charge and date as well as their interaction were significant. Bulk-solution phosphate-P levels were higher for the higher charge of pre-plant phosphate-P (Fig. 3). As substrate levels declined over time for both pre-plant charges, the curves converged. The bulk-solution phosphate-P level at seven d for the 0.06 $kg·m^{-3}$ pre-plant phosphate-P charge was 64.5 in this experiment compared to 90.4 in Expt. 1. The number of days for bulk-solution phosphate-P to decline to 3 $mg·L^{-1}$ were 26 and 37 for the 0.03 and 0.06 $kg·m^{-3}$ pre-plant phosphate-P charges, respectively. In the first experiment, 41 d were provided by the 0.06 $kg·m^{-3}$ pre-plant phosphate-P charge. The more rapid decline in bulk-solution phosphate-P level by 4 d in the second experiment can be attributed in part to better environmental conditions that led to increased growth and associated phosphate-P demand.

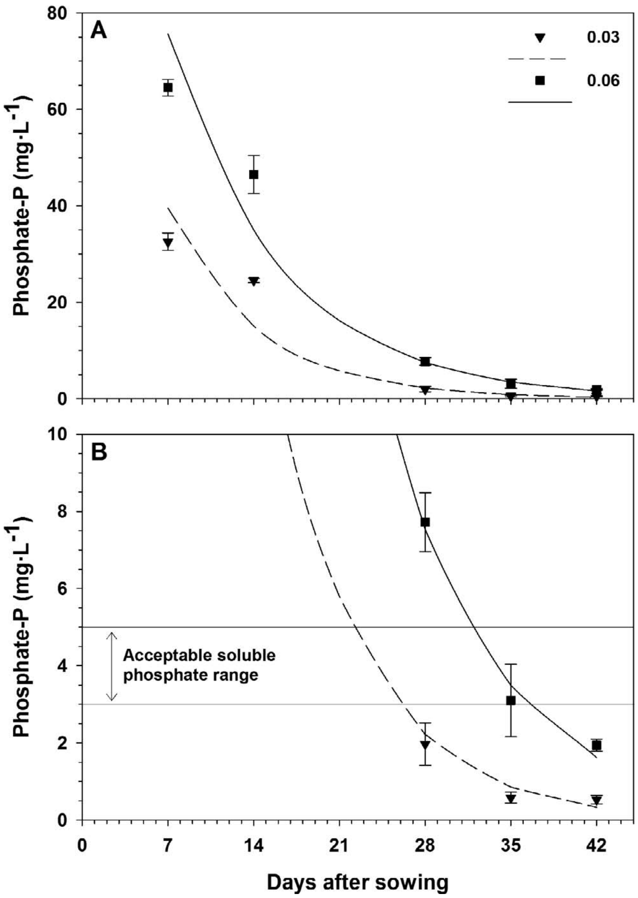


**Fig. 3. Effects of two pre-plant phosphorus (P) charges (0.03 and 0.06 kg·m$^{-3}$ equivalent to 0.05 and 0.10 lbs·yd$^{-3}$, respectively) under 20% leaching fraction on the mean bulk-solution phosphate-P concentration of the soilless substrate from 7 to 42 days after sowing petunia for plants grown in 288-cell plug trays in Expt. 2. Figure 3B is an expansion in the range from 0 to 10 mg·L$^{-1}$ (ppm) phosphate-P of the data shown in Fig. 3A. The acceptable bulk-solution phosphate-P range of 3 to 5 mg·L$^{-1}$ (ppm) presented by Warncke and Krauskopf (1983) is indicated. The regression equations generated from the best fit models were: $y_{0.03} = 103 \times 0.872^x$ ($r^2 = 0.93$) and $y_{0.06} = 163 \times 0.896^x$ ($r^2 = 0.96$). Vertical bars indicate ± S.E. (n = 4).**

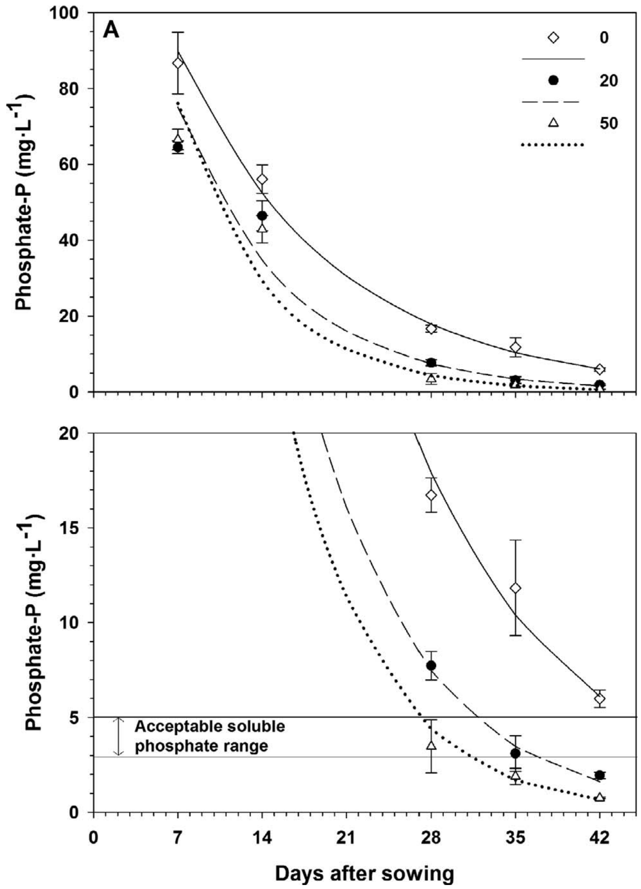


**Fig. 4. Effects of three leaching fraction treatments (0, 20, and 50%) with a pre-plant phosphorus (P) charge of 0.06 kg·m$^{-3}$ (0.10 lbs·yd$^{-3}$) on the mean bulk-solution phosphate-P concentration of the soilless substrate from 7 to 42 days after sowing petunia for plants grown in 288-cell plug trays in Expt. 2. Figure 4B is an expansion in the range from 0 to 20 mg·L$^{-1}$ (ppm) phosphate-P of the data shown in Fig. 4A. The acceptable bulk-solution phosphate-P range of 3 to 5 mg·L$^{-1}$ (ppm) presented by Warncke and Krauskopf (1983) is indicated. The regression equations generated from the best fit models were: $y_0 = 154 \times 0.926^x$ ($r^2 = 0.95$), $y_{20} = 162 \times 0.896^x$ ($r^2 = 0.96$), and $y_{50} = 197 \times 0.873^x$ ($r^2 = 0.94$). Vertical bars indicate ± S.E. (n = 4).**

*Expt. 2 – leaching treatments.* There were significant main effects and interaction with time when three leaching treatments of 0, 20, and 50% were tested over 42 d, all at a pre-plant phosphate-P charge of 0.06 kg·m$^{-3}$ (Fig. 4). Time required for substrate phosphate-P to decline to 3 mg·L$^{-1}$ was >42, 37 and 31 d for 0, 20, and 50% leaching treatments, respectively.

*Expts. 1 & 2 - shoot P concentration.* There was a significant effect of pre-plant phosphate-P on shoot P concentration in Expt. 1 when 20% leaching was applied (Table 2). Mean shoot P concentration at 42 days after sowing increased with increasing pre-plant phosphate-P charge in the substrate (0.46%, 0.66%, and 0.83% P at 0.06, 0.12, and 0.18 kg·m$^{-3}$, respectively). There was also a significant effect of leaching on shoot P concentration in Expt. 1 when a pre-plant phosphate-P charge of 0.06 kg·m$^{-3}$ was applied. Mean shoot P concentration at 42 d after sowing decreased with increasing leaching with

**Table 2. Effect of pre-plant phosphate-P charge and leaching percentage on the concentration of P in petunia leaves for plants grown in 288-cell plug trays in Expts. 1 and 2.**

| | % P | |
|---|---|---|
| Treatment | Expt. 1 | Expt. 2 |
| *Pre-plant P charge (kg·m$^{-3}$)* [z] | | |
| 0.03 | - | 0.16 ± 0.00[y] |
| 0.06 | 0.46 ± 0.02 | 0.26 ± 0.03 |
| 0.12 | 0.66 ± 0.04 | - |
| 0.18 | 0.83 ± 0.02 | - |
| *Leaching (%)* | | |
| 0 | 0.59 ± 0.02 | 0.34 ± 0.03 |
| 20 | 0.46 ± 0.02 | 0.26 ± 0.03 |
| 50 | 0.32 ± 0.01 | 0.19 ± 0.00 |

[z]Pre-plant phosphate-P charges of 0.03, 0.06, 0.12 and 0.18 kg·m$^{-3}$ substrate are equivalent to 0.05, 0.10, 0.20 and 0.30 lbs·yd$^{-3}$, respectively. Also, 1.0 lb·yd$^{-3}$ single superphosphate supplies 0.053 kg·m$^{-3}$ P.

[y]Standard errors were calculated using PROC MEANS (n = 4).

0.59%, 0.46%, and 0.32% P at 0, 20, and 50% leaching, respectively. All the mean shoot P concentrations in Expt. 1, except at the greatest leaching percentage (50%), were within or nearly within the survey ranges reported for petunia of 0.47 to 0.93% by Mills and Jones (1996) for recently mature leaves and 0.40 to 0.75 by Santos et al. (2011) for shoot cuttings from mature plants. Although below the survey ranges, the mean shoot P concentration of 0.32% in the 50% leaching treatment was well above the minimum critical concentration for deficiency symptoms in immature petunia seeding shoots of 0.07% described by Gibson et al. (2007). Tissue analyzed in our study was physiologically similar to the immature seedling shoots tested by Gibson et al. (2007). Also, Mills and Jones (1996) and Santos et al. (2011) did not identify minimum critical levels whereas Gibson et al. (2007) did.

Resulting tissue P concentrations in Expt. 2 for the 0.03 and 0.06 $kg \cdot m^{-3}$ pre-plant phosphate-P charges after 42 d of growth were 0.16% and 0.26%, respectively (Table 2). The concentration associated with the 0.6 pre-plant charge was lower in Expt. 2 than in Expt. 1. Likewise, tissue P levels associated with leaching treatments of 0, 20, and 50% were lower than in Expt. 1 (0.34, 0.26, and 0.19%, respectively). All tissue P levels in Expt. 2 were above the minimum critical level reported by Gibson et al. (2007). Experiment 2 was conducted from mid-March to late April and the N and K fertilization levels were also increased during the last two weeks. This resulted in increased growth and a dilution of the shoot P concentrations in all treatments.

In summary, bulk-solution phosphate-P longevity is influenced by size of phosphate charge, leaching, and season. In winter, 41 d longevity was achieved with a phosphate-P charge of 0.06 $kg \cdot m^{-3}$ and 20% or less leaching while in the spring longevity was 4 d less with this treatment. Reducing leaching to 0% extended the longevity to beyond 42 d in both seasons.

## Literature Cited


Barrett, J. 1992. These simple tests help determine whether you use the right medium. Greenhouse Manager, 11:63.

Bunt, A.C. 1976. Modern Potting Composts: A Manual on the Preparation and Use of Growing Media for Pot Plants. The Pennsylvania State University Press, University Park, PA. p. 151–162.

Chapman, H.D., and P.F. Pratt. 1961. Methods of analysis for soils, plant, and waters. University of California, Division of Agricultural Sciences, pp 169–170.

Dole, J.M., and H.F. Wilkins. 2005. Floriculture: Principles and Species 2nd ed. Pearson Prentice Hall, Upper Saddle River, NJ. pp. 10–18, 418, 812.

Gibson, J.L., D.S. Pitchay, A.L. Williams-Rhodes, B.E. Whipker, P.V. Nelson, and J.M. Dole. 2007. Nutrient Deficiencies in Bedding Plants: A pictorial guide for identification and correction. Ball Publishing, Batavia, IL. p. 7, 280–282.

Handreck, K. and N. Black. 2002. Growing Media for Ornamental Plants and Turf 3rd ed. University of New South Wales Press, Sydney, Australia. p. 173.

Hansen, C.W., and J. Lynch. 1998a. Response to phosphorus availability during vegetative and reproductive growth of chrysanthemum: I. Whole plant carbon dioxide exchange. J. Amer. Soc. Hort. Sci. 123(2):215–222.

Hansen, C.W., and J. Lynch. 1998b. Response to phosphorus availability during vegetative and reproductive growth of chrysanthemum: II. Biomass and phosphorus dynamics. J. Amer. Soc. Hort. Sci. 123(2):223–229.

Henry, J.B. 2017. Beneficial and adverse effects of low phosphorus fertilization of floriculture species. MS Thesis, N.C. State Univ., Raleigh, NC. p. 113, 158.

Khandan-Mirkohi, A. and M.K. Schenk. 2009. Phosphorus efficiency of ornamental plants in peat substrates. J. Plant Nutr. Soil Sci. 172(3):369–377.

Lindsay, W.L. 1979. Chemical equilibria in soils. John Wiley & Sons, New York, NY. p. 165.

Marconi, D.J., and P.V. Nelson. 1984. Leaching of applied phosphorus in container media. Sci. Hort. 22:275–285.

Mills, H.A., and J.B. Jones. 1996. Plant Analysis Handbook II. Micro-Macro Publishing, Inc., New York. p. 194.

Murphy, J., and J.P. Riley. 1962. A modified single solution for the determination of phosphate in natural waters. Anal. Chim. Acta 27:31–36.

Nelson, P.V., C.Y. Song, J.S. Huang, C.E. Niedziela Jr., and W.H. Swallow. 2012. Relative effects of fertilizer nitrogen form and phosphate level on control of bedding plant seedling growth. HortScience 47(2):249–253.

Santos, K.M., P.R. Fisher, and W.R. Argo. 2011. Survey of tissue nutrient levels in vegetative cuttings. Comm. Soil. Sci. Plant Anal. 42(6): 669–693.

Styer, R.C., and D.S. Koranski. 1997. Plug and Transplant Production: A Grower's Guide. Ball Publishing, West Chicago, IL. pp. 289–294.

Warncke, D.D. and D.M. Krauskopf. 1983. Greenhouse growth media and nutrition guidelines. Mich. State Univ. Coop. Ext. Ser. Bul. E-1736. p. 1.

Whipker, B. 2014. Garden mums: Upper leaf yellowing and necrosis. e-GRO Alert 3-62. p. 7. http://www.e-gro.org/pdf/362.pdf. Accessed April 15, 2017.