Buffered Phosphorus Fertilizer Improves Growth and Drought Tolerance of Woody Landscape Plants[1]

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Abstract

The effects of alumina-buffered phosphorus (Al-P) were evaluated on growth and drought tolerance of woody plants and on seedling establishment of several tree species grown in containers with soilless media. Al-P reduced phosphorus leaching in all species. Vegetative growth of rhododendron (*Rhododendron catawbiense* Michx. cv. 'English Roseum'), forsythia (*Forsythia intermedia* Zab. cv. 'Spring Glory'), Ohio buckeye (*Aesculus glabra* Willd.), and bur oak (*Quercus macrocarpa* Michx.), measured as plant height, stem caliper, or biomass, was as fast or faster with Al-P as with Osmocote (17–6–10) or monoammonium phosphate fertilizer. Imposition of summer drought during the first growth season slightly reduced growth of rhododendron, with a stronger effect in the second year, while forsythia was more affected in the first season. Rhododendron plants fertilized with Al-P wilted more slowly than controls fertilized with Osmocote. Al-P fertilized forsythia plants grew faster than controls whether drought was imposed or not. Rhododendron plants produced more flower buds in the first year when fertilized with Al-P than with conventional phosphorus fertilizers. At the lower desorbing concentration, drought caused no reduction in percent of plants producing flower buds. A recharging treatment was tested at the beginning of the second season to replace P lost from the Al-P. Recharged Al-P reduced branching and flowering of rhododendron at the end of the second season, possibly as a result of damage from the recharging treatment.

Index words: leaching, forsythia, rhododendron, Ohio buckeye, bur oak.

Species used in this study: rhododendron (*Rhododendron catawbiense* Michx.); forsythia (*Forsythia intermedia* Zab.); Ohio buckeye (*Aesculus glabra* Willd.); bur oak (*Quercus macrocarpa* Michx.).

Significance to the Nursery Industry

Applying slow-release fertilizers to soilless media is common nursery practice in container-grown ornamental woody plant production. Phosphorus release from these fertilizers depends on time, temperature and moisture, rather than plant demand. High phosphorus may result in reduced plant quality, and excess phosphorus is leached from containers into surface and ground water systems during irrigation, causing environmental pollution. Phosphorus effluent from agricultural production is the subject of increasing regulatory pressure from federal and state agencies.

This report describes the use of a novel phosphorus fertilizer (Al-P) that maintains constant, low levels of phosphorus in the root zone. These low levels reduce phosphorus leaching while maintaining vigorous plant growth. Rhododendron plants grown with Al-P wilted more slowly during drought and had better root development, and forsythia plants grew more quickly with or without drought. A higher percentage of rhododendron plants produced flowers in the first year when grown with Al-P rather than with conventional fertilizers. The benefits of using this fertilizer include improved plant quality and reduced phosphorus release from nurseries.

Introduction

Nurseries and greenhouses typically use resin-coated slow-release phosphorus fertilizers such as Osmocote® for container-grown woody plant production. Nutrients are released from these fertilizers based on temperature and moisture rather than plant requirements (4). Lack of synchronization between nutrient release and plant nutrient demand can result in periods of excess nutrient supply early in the growing season and periods of nutrient deficiency later in the growth cycle. Excess supply can inhibit plant growth through direct effects of surplus phosphorus on root growth as well as indirect effects of excess phosphorus on the availability of other nutrients, especially calcium and zinc (10). Periods of excessive nutrient supply also may result in environmental pollution if phosphorus-laden irrigation water escapes the production system. Phosphorus effluents from agricultural production systems are increasingly subject to federal and state regulations for the protection of water quality (6). Therefore, alternative fertilization systems that more closely synchronize phosphorus supply and demand are needed.

Solid-phase buffered phosphorus (Al-P), a novel phosphorus fertilizer that dynamically provides phosphorus to plant roots based on actual plant phosphorus requirements (9), has been evaluated in soilless culture of flowers including marigold (*Tagetes patula*) and impatiens (*Impatiens wallerana*) (1, 2, 7), and shrubs including rhododendron (*Rhododendron catawbiense*) and forsythia (*Forsythia intermedia*) (3). With Al-P, phosphorus leaching is dramatically reduced compared with conventional fertilization methods (1, 3, 7). Lin *et al*. (7) found that marigolds grown with Al-P produced higher biomass compared to marigolds grown using commercial fertilizers. Borch *et al*. (1) reported that marigold and impatiens plants grown with the Al-P fertilizer were more resistant to drought than conventionally grown plants, and floral wilting was reduced for both species grown with Al-P. In addition, marigold plants grown with Al-P produced more flowers, and their roots were more evenly distributed through the medium. Al-P improved growth of two woody species, forsythia and rhododendron during a single season compared

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with soluble or slow-release phosphorus fertilizers (3). For forsythia, the highest shoot dry mass was obtained from mixing Al-P with the growth medium at 0.5% w/v; while for rhododendron, the 1.0% Al-P treatment resulted in the largest plants. In this paper, we describe the growth responses to Al-P of rhododendron and forsythia plants over two growing seasons and after the imposition of drought stress. We hypothesized that woody plants, like bedding plants, may be more tolerant of drought stress when grown with Al-P.

We have also tested the effects of Al-P fertilization on the growth of young tree seedlings. Culture of such seedlings may provide the industry with an improved method to produce container-grown shade trees. However, one difficulty of doing so is that seedlings of some tree species establish a long taproot. When this root is cut during transplanting, the tree may take several years to establish an adequate root system. We found that low phosphorus availability stimulated the root growth of common bean (*Phaseolus vulgaris* L.), marigolds, and other species (1, 6, 8). Therefore, low but consistent phosphorus supplied by Al-P might be beneficial to establishment of tree seedlings by improving root proliferation.

Materials and Methods

One-year-old rooted cuttings of rhododendron (*Rhododendron catawbiense* Michx. cv. 'English Roseum') and forsythia (*Forsythia intermedia* Zab. cv. 'Spring Glory') were purchased from Appalachian Nurseries, Inc., Waynesboro, PA, in spring 1999. Ohio buckeye (*Aesculus glabra* Willd.) and bur oak (*Quercus macrocarpa* Michx.) seeds were collected in the fall of 1998 from trees growing in State College, PA, and stratified in moist peat moss at 3C (37.4F) for three months. Seeds were planted on February 25, 1999, in D-40 DeePots (DeePots™, Stuewe & Sons, Inc., 2290 SE Kiger Island Drive, Corvallis, OR) in Sunshine No. 4 medium (Canadian Sphagnum peat moss, perlite, gypsum, and dolomitic lime, J.R. Johnson Supply, Inc., 2582 Long Lake Road, St Paul, MN). Fertilizer (21–7–7, with micronutrients) solution was applied twice per week to supply 2 mM (60 ppm) N for the first month and 3 mM (90 ppm) N for the second month. Germination and cultivation were carried out in a Pennsylvania State University greenhouse located in University Park, PA (longitude: W77.8, latitude: N40.8). Day-night average temperature was maintained in the range of 28~18C (82.4~64.4F).

On May 13, 1999, seedlings were transplanted to #2 nursery pots (2 gal or 7.6 liter, size 8.5 × 8.5 in or 21.6 × 21.6 cm). The inside of the pots was painted with Spinout (Griffin Corp., Valdosta, GA, active ingredient 7.1% copper hydroxide in latex paint) prior to planting. The growth medium was Fafard Mix No. 52 (Fafard Peat Moss Co., Ltd., 422 Chemin Pallot, Inkerman, NB, Canada), consisting of processed pine bark (60%), Canadian sphagnum peat, and vermiculite. Phosphorus was supplied from mono-ammonium phosphate (MAP 12–61–0), Osmocote 17–6–10 plus, or Al-P fertilizers prepared with desorbing concentrations of 74 µM phosphorus (Al-P/74) or 127 µM phosphorus (Al-P/127) according to Lynch *et al*. (9). These were mixed with the medium together with other fertilizers to obtain comparable supply of all nutrients except phosphorus (Table 1). Nitrogen and potassium were supplied to the Al-P treated plants with slow release single-nutrient fertilizers: Osmocote 36–0–0 (sulfur-coated urea) and Osmocote 0–0–44 (coated potash).

Table 1. Fertilizer treatments for rhododendron, forsythia, bur oak, and buckeye.

	Fertilizer treatment (g/L media)			
Sources of nutrient	**MAP**[z]	**Osmocote**	**Al-P/74**	**Al-P/127**
MAP 12–61–0	0.5	0	0	0
Osmocote 17–6–10 plus	0	5	0	0
Osmocote 36–0–0	2.5	0	2.5	2.5
Osmocote 0–0–44	1.25	0	1.25	1.25
MicroMax	1	0	1	1
Pelletized lime	0.4	0	0.4	0.4
Al-P 74 µM [y]	0	0	10	0
Al-P127 µM [y]	0	0	0	10

[z] Monoammonium phosphate (MAP) treatment not included for rhododendron and forsythia.

[y] P desorption rate.

Plants were grown outdoors at Penn State's Russell E. Larson Research Facility in Rock Springs, PA, under daily irrigation during the growth season. Plants were covered between December 9, 1999, and February 20, 2000, with plastic ThermoBlanket (Cady Bag Co., Inc. PO Box 68, Pearson, GA) to protect the roots. In June 2000, Al-P was recharged by adding a 5 mM KH_2PO_4 solution (pH 5.2) at 1 liter/pot for Al-P/127, and 2.5 mM for Al-P/74. Pots were leached thoroughly after 2 days. At the same time, all other fertilizers were re-applied to the top of the medium at the same rate as in the first year. There was no irrigation during recharging. The phosphorus content of the irrigation water was 0.4 µM in the greenhouse and 0.07 µM at Rock Springs.

Every two weeks during the growing season, leachate samples were collected from saucers beneath all pots 15 min after irrigation with 500 ml water in addition to the daily irrigation. Phosphorus concentration in leachate was measured according to Murphy & Riley (11). The pH values and total dissolved solid (TDS) of the leachate samples were also measured (pHTestr2 for pH and TDSTestr4 for TDS, Oakton Instruments, P.O. Box 5136, Vernon Hills, IL).

Drought treatment of rhododendron and forsythia started on August 9, 1999, and lasted for 2 weeks. Plants were placed in a shed covered with transparent plastic film (roof only). During the study, stomatal conductance of leaves was monitored with a steady state porometer (Model LI-1600, LI-COR, Inc., Lincoln, NE) around 10 AM every day until values became too low to measure. The date of visible wilting was recorded. During the drought treatment, the mean daily temperature ranged from 16~23C (61~73F) and the relative humidity was from 65–90%.

Plant height and stem caliper of all species, flower bud number of rhododendron and forsythia, and shoot and root weight of forsythia were measured at the end of November in 1999 and 2000. Plant height was measured from the surface of the medium to the top of the plant. For stem caliper measurement, stems were marked 2–3 cm (0.8–1.2 in) above the medium with a permanent mark, and the same place was measured with a caliper after 2 years. Forsythia shoots were pruned to a height of 15 cm, and fresh weight (FW) and dry weight (DW) of pruned branches were recorded. For leaf analysis, fully expanded leaves were collected, dried in an oven at 60C (140F), and dried samples were analyzed at Penn State's Agricultural Analytical Services Laboratory.

For buckeye and bur oak, a single factor (fertilizer treatment) randomized block design was used. For rhododendron and forsythia, a second factor, drought, was combined with the factor of phosphorus fertilizer in a two-factor randomized block design. Each treatment was replicated 3 times with 4 plants per replication serving as subsamples, for a total of 12 plants per treatment. Data were analyzed by ANOVA, least standard deviation (LSD), and t-tests using the statistical software package MiniTab® (Minitab Inc., 3081 Enterprise Drive, State College, PA).

Results and Discussion

Al-P reduced phosphorus leaching. The phosphorus levels in leachate from plants of all species grown with Al-P were stable and low in comparison with Osmocote or MAP in both 1999 and 2000 (Fig. 1). Phosphorus released from Osmocote treated pots increased during the 1999 season, reaching a peak in mid-summer and then decreasing as temperature dropped (Fig. 1). The phosphorus level in leachate from pots with MAP was 1791 ± 209 µM at the first measurement in 1999, a level about one order of magnitude higher than that from other treatments, and then decreased sharply in the second and third samplings (Fig. 1). As shown previously (3), plants grown with Al-P maintained a relatively low and steady rate of phosphorus leaching within the range of 1.3 to 79.0 µM phosphorus (Fig. 1).

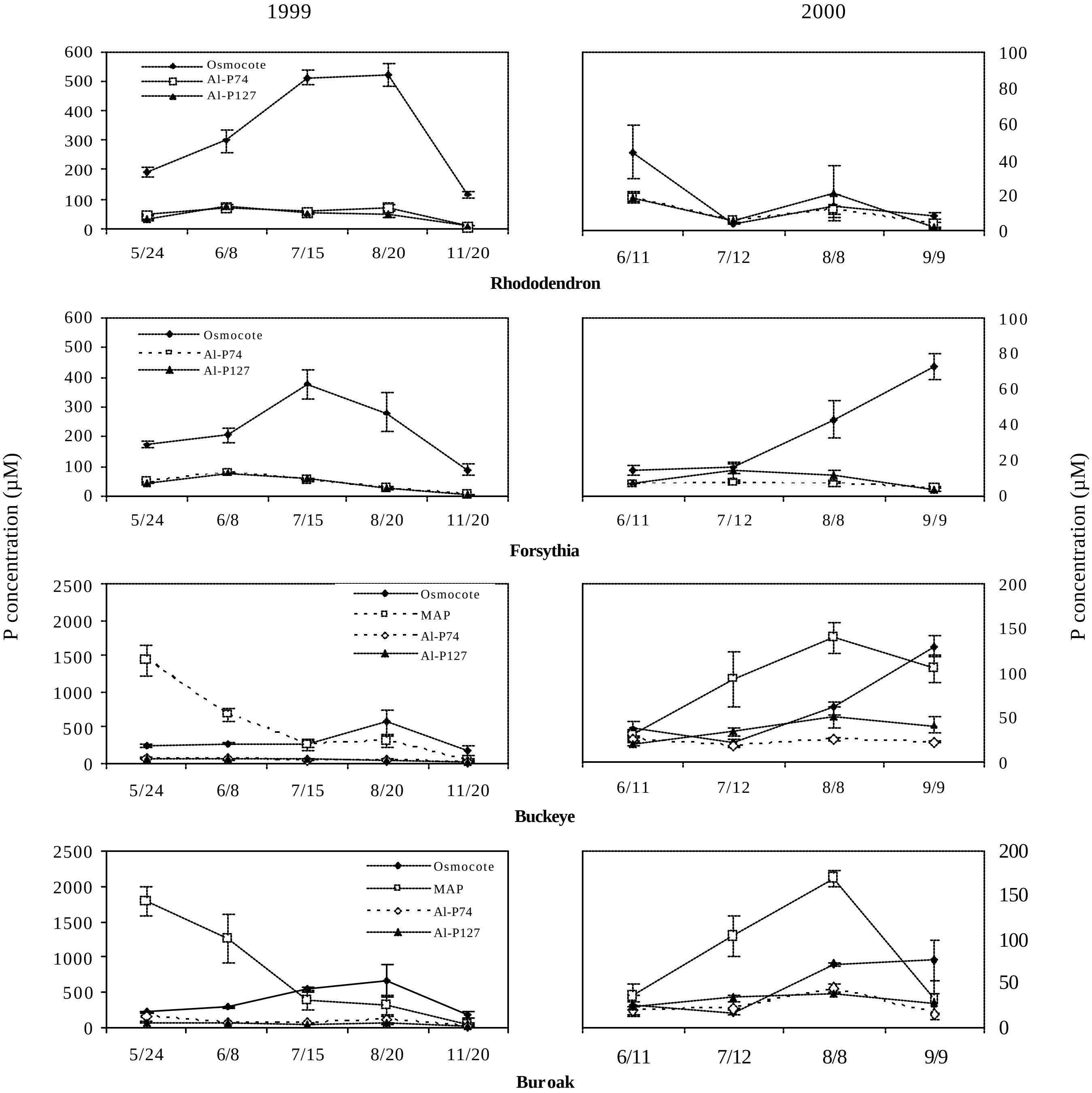

Fig. 1. P concentration of leachate from plants grown with Osmocote, MAP, or Al-P desorbing at 74 or 127 µM. Bars represent standard errors of means. Figures in left column are for the 1999 season, and the right column is for the 2000 season. X coordinate values are the sampling dates in month/day format. Note variations in scale of the Y-axes.

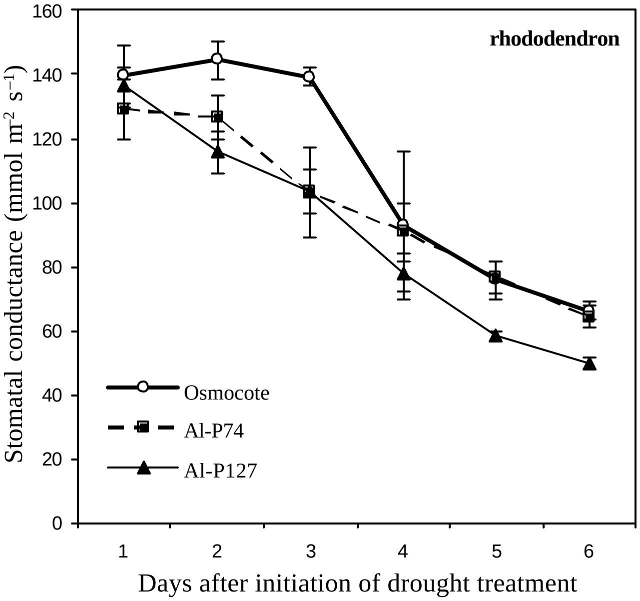

Fig. 2. Stomatal conductance of rhododendron leaves during drought stress. Bars represent standard error of mean.

At the beginning of the second season, additional MAP or Osmocote was added to the surface of the medium. Phosphorus leaching during the second season was considerably less than in the first season, when fertilizers were incorporated, but continued to be higher from Osmocote or MAP treated plants than from Al-P treated plants (Fig. 1). For example, the leachate sample of Osmocote treatment for forsythia on September 9, 2000, contained 72.7 µM phosphorus, much higher than Al-P/74 (3.9 µM) and Al-P/127 (3.4 µM) treatments. We estimate by integrating the phosphorus leaching curve that Al-P reduced leaching by 86–88% compared with the control (Osmocote) for rhododendron and forsythia in 1999, and by 56–59% for rhododendron and 72–78% for forsythia in 2000. Total dissolved solids and pH of leachate samples were the same for AL-P and Osmocote fertilized pots (data not shown). For all phosphorus fertilizer treatments and all species, pH value in the leachate was maintained in the range of 6.0–6.5.

Since phosphorus in the Al-P fertilizer would eventually become depleted, we recharged the Al-P *in situ* early in the 2000 season by adding 1 liter of 5 mM KH_2PO_4 solution to each pot, leaving it for 2 days, then leaching. After the *in situ* phosphorus recharging of alumina, both rhododendron and forsythia showed leaf chlorosis, with more severe symptoms in forsythia. Leaf analysis indicated that Al-P grown plants of both species contained much higher K (0.96% vs. 0.66% for forsythia; 0.92% vs. 0.71% for rhododendron) and Mn (µg/g: 772 vs. 608 for forsythia; 1272 vs. 416 for rhododendron) than controls, but P levels were not different between recharged Al-P and Osmocote-fertilized plants (0.12% for forsythia; 0.10% for rhododendron). The recharging solution contained a high concentration of K^+, which may have temporarily altered rhizosphere pH or microbial population following the period of recharging, leading to greater Mn uptake. The chlorosis disappeared in two weeks. Reapplication of Osmocote and MAP did not cause any visible phytotoxic effects. Further study is needed to optimize phosphorus recharging, including the use of lower concentrations of KH_2PO_4, and/or a shorter duration of recharging.

Drought stress response. Rhododendron plants grown with Al-P, especially at the low rate, wilted more slowly under drought stress than those grown with Osmocote. For example, of 12 plants treated with Al-P/74, Al-P /127 or Osmocote, 4, 7, and 9 plants, respectively, had wilted by day 8 of the drought treatment. All plants recovered from the drought treatment. The earlier stages of water stress were monitored by measuring stomatal conductance (Fig. 2). The higher stomatal conductance rate during the early part of the drought treatment for plants grown with Osmocote indicated that leaf stomata did not respond to drought as quickly as Al-P plants, which may have affected their ability to avoid water loss under stress. In plants that had been fertilized with Osmocote, young shoots were still growing when drought stress started, while all shoots from Al-P treated plants had formed top buds. This difference in phenology may have affected the differences in time to wilting observed among the treatments.

Two-factor ANOVA (phosphorus level and drought) shows that phosphorus treatments did not affect rhododendron caliper or height in either 1999 or 2000 (Table 2). This result suggests that Al-P provided adequate phosphorus for growth in terms of caliper and height. However, branching (assessed as total buds, since there were no blind shoots) was significantly reduced in the Al-P treatments in the second year (Table 2, Fig. 3). The reduction in branching of Al-P treated plants in the second year may have been caused by damage from the Al-P recharging treatment, described above. Another possibility could be that the Al-P fertilized plants did not receive adequate phosphorus during the second season. Except the first measurement, phosphorus concentration in the leachate with Al-P treatments was below 20 µM throughout the 2000 season (Fig. 1). However, leaf analysis showed no significant differences in tissue phosphorus concentrations among treatments (data not shown). Phosphorus concentrations were always in the range 0.10–0.12%, and growth (measured as stem caliper and height) was not significantly reduced by Al-P (Table 2), indicating that phosphorus supply was adequate. Drought treatment imposed during 1999 significantly reduced height in both years and stem caliper at the end of 2000, but there was no interaction with phosphorus treatment (Table 2, data not shown).

Reproductive development was significantly affected by phosphorus treatment and drought (Tables 2 and 3). More plants grown with Al-P than with conventional phosphorus fertilizers produced flower buds in the first year, and at 74 µM Al-P there was no effect of drought on flower bud formation. At the end of the 2000 season, all plants produced flower buds, but Al-P fertilized plants produced fewer

Table 2. P-values of two factor ANOVA for size and bud number of rhododendron plants grown with various phosphorus (P) treatments with and without drought imposed in summer 1999. Total bud number includes floral and vegetative buds. P values < 0.05 are considered significant.

	P values from ANOVA					
	1999		2000			
Factor	caliper	height	caliper	height	Flower buds	Total buds
P	0.559	0.077	0.310	0.258	0.004	< 0.001
Drought	0.321	0.018	0.015	0.020	0.900	0.011
P × drought	0.258	0.088	0.940	0.587	0.951	0.163

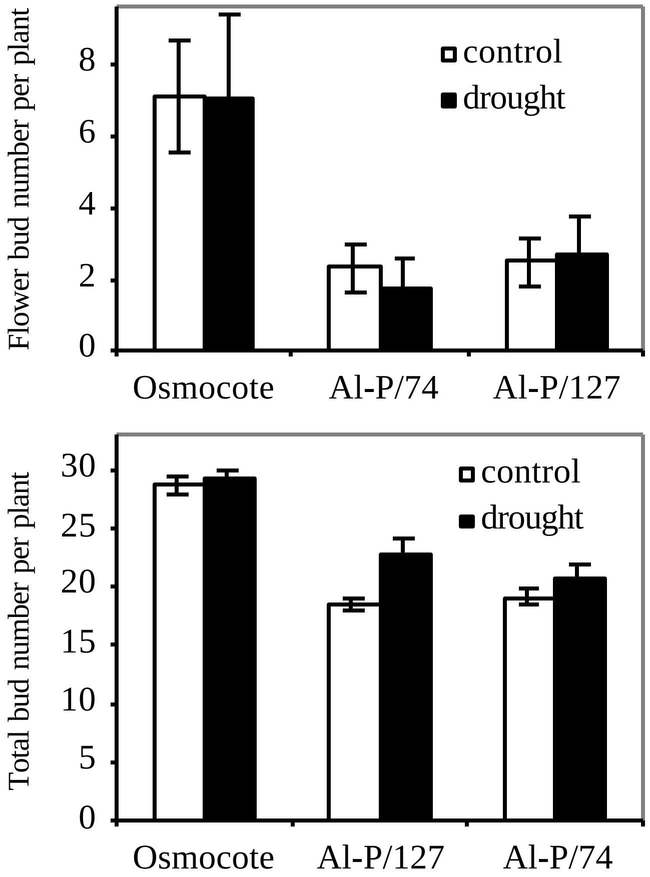

Fig. 3. Rhododendron flower bud number and total bud number (flower buds + vegetative buds = total buds = total shoots) at the end of 2000. Values shown are means of 12 plants per treatment ± standard error of mean. ANOVA results for this data are shown in Table 2.

branches and fewer flower buds than plants grown with Osmocote (Fig. 3). In addition, the proportion of shoots with flower buds rather than vegetative buds was 12–13% for Al-P plants and 24% for Osmocote-fertilized plants. The proportion of flower buds was unaffected by drought except in Al-P/127 plants, in which only 8% of buds were reproductive.

We observed more extensive root growth of rhododendron from Al-P treatments (Fig. 4). Fine roots completely filled the medium throughout the pot for Al-P treatments, but barely penetrated into the lower half of the pot in the Osmocote treatment. The difference in root growth could have been responsible for the differences in flowering.

Table 3. Percentage of rhododendron plants bearing flower buds at the end of 1999. In 2000 all plants produced flower buds.

P source	Treatment	% Plants with flower buds ^{z}
Osmocote	Drought	8.3
Osmocote	Control	16.7
Al-P74	Drought	75.0
Al-P74	Control	75.0
Al-P127	Drought	16.7
Al-P127	Control	41.7

^{z}Percent calculated from 12 plants.

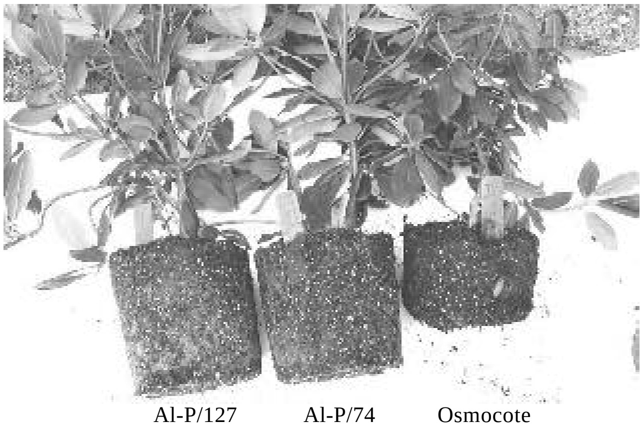

Fig. 4. Typical appearance of roots grown with Osmocote or Al-P treatment. Treatment (left to right): Al-P/127, Al-P/74, and Osmocote. The root ball of Osmocote treatment is about half of that in two Al-P treatments. Photo was taken on October 7, 2000.

For forsythia, there was no difference among treatments in time to wilting during drought stress, and all plants wilted during the drought treatment but survived (data not shown). The stomatal conductance of plants grown with Osmocote was lower than that of Al-P plants at days 1 and 2 (Fig. 5). Since we did not measure initial stomatal conductance in freshly-irrigated plants, we do not know if this was a pre-existing difference or whether the Osmocote fertilized plants responded very quickly to the drought stress. The former possibility seems more likely because the plants were irrigated daily, so plants were not likely to be water stressed only 24 hr after the last irrigation.

The fresh weight of pruned tissue, collected when forsythia plants were pruned to 15 cm (6 in) at the end of each growing season, was higher for plants fertilized with Al-P than for plants fertilized with Osmocote in 1999, while in 2000 there was no significant P-treatment effect (Table 4, Fig. 6). Drought reduced fresh weight of pruned tissues in plants fertilized with Osmocote, Al-P/74 and Al-P/127 by 52%, 37%, and 25%, respectively, at the end of the first season. In the second year after drought, plants had recovered from the drought treatment, and there was no significant difference in growth between drought and irrigated treatments according

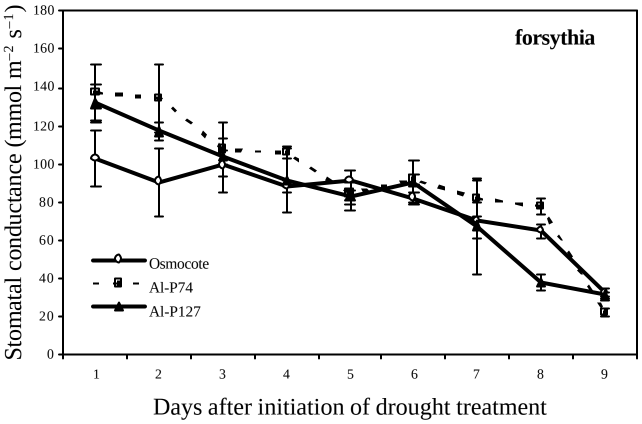

Fig. 5. Stomatal conductance of forsythia leaves during drought stress. Bars represent standard error of mean.

Table 4. P-values of two factor ANOVA for fresh weight of pruned shoots of forsythia plants grown with various phosphorus (P) treatments with and without drought imposed in summer 1999. Shoots were pruned back to 15 cm at the end of each growing season. P values < 0.05 are considered significant.

	P values for shoot FW	
Factor	**1999**	**2000**
P	<0.001	0.068
Drought	<0.001	0.086
P × drought	0.482	0.210

to the ANOVA (Table 4), and only a slight difference according to Fisher's PLSD (P = 0.049). In the absence of drought, forsythia plants fertilized with Al-P/74 had the highest shoot growth of all treatments. Leaves of plants from all treatments had tissue phosphorus concentrations between 0.10 and 0.12%.

In an experiment testing Al-P mixed at different rates with a bark, vermiculite, and perlite medium, Brown *et al.* (3) reported that the highest biomass of forsythia was from the treatment fertilized with 0.5% (w/v) Al-P (desorption rate at 200 µM), while for rhododendron, 1% Al-P gave a higher biomass production. In this experiment, we used much lower desorption rates of Al-P (127 and 74 µM) at only one mixing rate (1% w/v). In this experiment, rhododendron plants fertilized with Al-P at either desorption rate produced more shoot growth and a greater flower bud number than Osmocote treated plants after one season of growth (Table 3), which may be desirable for marketing. For forsythia, there was no difference in flower production between Al-P and Osmocote plants (data not shown), but Al-P /74 plants accumulated the most shoot biomass (Fig. 6). The results from this paper and from Brown *et al.* (3) indicate that forsythia growth is optimal at lower phosphorus availability.

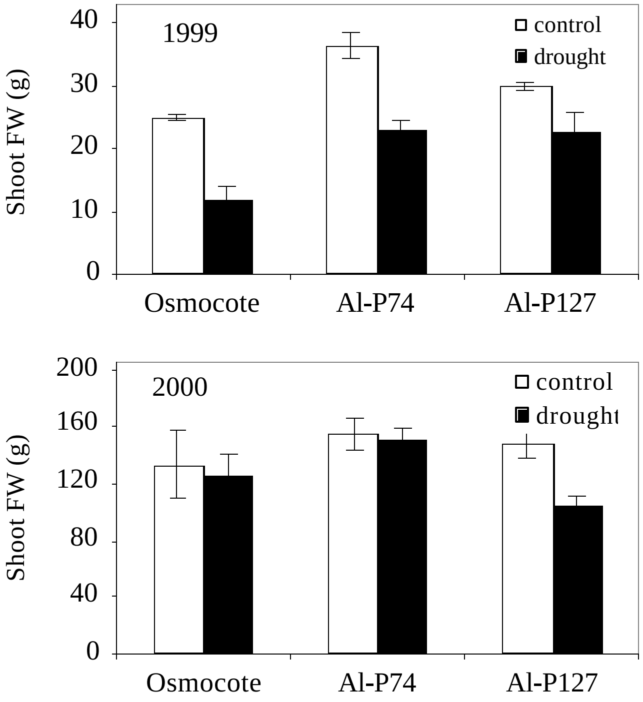

Fig. 6. Pruned shoot fresh weight of forsythia after cutting back to 15 cm at the end of each season. Bars represent standard error of mean. ANOVA results for this data are shown in Table 4.

Growth of tree seedlings fertilized with Al-P. The growth (stem caliper and plant height) of buckeye and bur oak was not affected by phosphorus source, though buckeye grown with Al-P/74 produced a slightly taller plant (data not shown). During the experiment, buckeye grew slowly. For example, at the end of the 2 seasons of growth in this experiment, the average plant height was below 20 cm (7.8 in). Bur oak plants were taller (the average plant height was in the range 55–75 cm (21.6–29.5 in)), but plants usually did not branch. Al-P provided adequate phosphorus for growth of these species with reduced leaching but did not provide visible improvement in growth during the seedling stage.

Conclusions

- Al-P substantially reduced phosphorus leaching from containerized woody plants compared with slow-release fertilizer (Osmocote) and conventional soluble fertilizer (MAP).
- Al-P with a desorption rate of 74 µM provided adequate phosphorus for growth of woody plants.
- Al-P promoted flower production in rhododendron in first year.
- Al-P increased growth rate of forsythia even when plants were exposed to drought.

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