Table 2. The effect of site on weight of shoots and primary lateral roots during two growing seasons, and the number of primary lateral roots per tree after the second growing season.

Site	Current season's shoot growth per tree (g)		Root wt per tree (g)		Roots per tree (no.)
	1994	1995	1994	1995	
Perkins	4	26	2	9	10
Sparks	11	64	14	18	9
Significance	*	*	*	*	NS

*Significant at $P = 0.05$.

Table 3. The effect of taproot length on primary lateral root weight per pecan tree during two growing seasons, and on the number of primary lateral roots per tree after the second growing season.

Taproot length (ft)	Root wt per tree (g)		Roots per tree (no.)
	1994	1995	
1	12	23	13
2	6	7	8
3	4	7	6
Linear	*	***	**
Quadratic	NS	*	NS

Significant at $P = 0.05$, 0.01 , or 0.001 .

root growth is inhibited by high concentrations of auxin (Westwood, 1993). Root number decreased with increasing taproot length (Table 3) while total shoot growth varied with site and taproot length (Table 1). Shoot growth from the Sparks site was greatest from 2-ft taproots in 1994 and from 1 ft taproots in 1995 (Table 1). Trees at the Perkins site, however, produced more shoot growth from longer taproot trees (Table 1) which had fewer branch roots (Table 3). This difference could have been due to soil differences, e.g., texture, aeration or water holding capacity, as suggested by Smith and Johnson (1981) or to auxin imbalance between the top and root. These determinations were beyond the scope of this experiment.

Similar to the findings of Wood (1996) taproot length did not affect shoot dry weight at either location (data not presented). As taproot length increased, the dry weight and number of roots produced decreased (Table 3).

Conclusions

Wounding of the taproot other than cutting to length was not beneficial. Pruning the taproot before transplanting a bare root pecan tree stimulates primary lateral root and shoot growth the first 2 years after transplanting. The ideal taproot length varies with site. In light-textured soils with potential for water shortage at shallow depths, longer taproots appear to be warranted. In heavier or well-irrigated soils, a taproot cut to ≈ 1 ft seems to be the best choice.

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Improving Bedding Plant Quality and Stress Resistance with Low Phosphorus

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ADDITIONAL INDEX WORDS. drought, *Impatiens wallerana*, plant nutrition, postproduction quality, *Tagetes patula*, phosphorus

SUMMARY. Bedding plants are frequently exposed to water stress during the postproduction period, resulting in reduced quality. We demonstrated that alumina-buffered P fertilizer (Al-P) provides adequate but much lower P concentrations than conventionally used in soilless mixes. When *impatiens* (*Impatiens wallerana* Hook. f. 'Impulse Orange') and marigold (*Tagetes patula* L. 'Janie Tangerine') plants were grown with reduced phosphorus using Al-P, P leaching was greatly reduced and plant quality was improved. Diameter of *impatiens* plants and leaf area of plants of both species were reduced by Al-P. Marigold plants grown with Al-P had more flowers and fewer wilted flowers. Flower wilting was also reduced for *impatiens* plants grown with Al-P. In marigold plants, roots were confined to a small volume beneath the drip tube in control plants, while roots of Al-P plants were well distributed through the medium. There was no obvious difference in *impatiens* root distribution. When plants at the marketing stage were exposed to drought, the Al-P plants of both species wilted more slowly than the conventionally fertilized controls. The reduced leaf area in both species

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and the improved root distribution of marigold may account for the improvement in drought tolerance of the Al-P plants.

To increase consumer satisfaction, growers must produce high-quality plants that are compact, stress tolerant, and free from diseases. Plants with uniformly distributed, well-developed root systems are best at withstanding the fluctuations in soil moisture that occur during shipping and handling.

To keep the production period as short as possible, bedding plants are grown with optimum light and temperature and a surplus of fertilizer to maximize growth rate. However, these conditions often produce plants with elongated, lush shoots; poorly developed roots; and poor stress tolerance. Therefore, it is recommended that, before shipping, growers harden their plants with a short period of lower temperature, reduced fertilizer, and reduced water at the end of the production cycle (e.g., Serek, 1990). This practice is believed to increase stress resistance by encouraging root growth at the expense of shoot growth. It might be possible to improve plant quality and stress tolerance even more by encouraging strong root growth during production by reducing P levels in the root zone. Previous research has shown that high P levels (1 to 5 mM) commonly used in commercial floriculture inhibit root growth (J.P. Lynch, unpublished data) and studies using P-buffered solutions indicate that plants can grow well at P levels as low as 3 μM P (Lynch et al., 1991). When various concentrations of solid-phase Al-P were tested on marigold plants, there was no evidence of aluminum toxicity unless $\geq 12\%$ P-Al₂O₃ was added to the media (Lin et al., 1996). There was also some evidence for increased shoot branching, indicating that lower P may have positive effects on plant quality. The objective of this project was to investigate the effects of low P levels on development and quality of impatiens and marigold plants. We specifically tested the hypothesis that low P would improve resistance of these bedding plants to postproduction drought stress.

Materials and methods

Two species, impatiens and marigold, were germinated in December in

peat and grown in a greenhouse without supplemental light. Day and night temperature were 24.4 ± 2.4 °C and 20.9 ± 0.5 °C, respectively. Seedlings were transplanted to sphagnum peat (Premier Horticulture, Red Hill, Pa.) in 12-cm-diameter pots after 2 weeks. Before use, the peat was washed with distilled water until P concentrations were not detectable (<0.2 μM).

Plants were distributed at random among three P treatments: control and two Al-P treatments. Of the 23 plants in each P treatment, 12 were used for postproduction evaluations in a simulated consumer environment, of which six were subjected to simulated transport and six were not. The other 11 plants were kept in the greenhouse; six of these were subjected to drought and the other five were kept well irrigated.

Control plants (high P) were fertilized at each irrigation with a nutrient solution containing a P concentration of 1.5 mM from NH₄H₂PO₄ and the following nutrients (in μM): 125 (NH₄)₂SO₄, 3000 KNO₃, 2000 Ca(NO₃)₂, 500 MgSO₄, 25 KCl, 12 H₃BO₃, 1 MnSO₄, 1 ZnSO₄, 0.25 CuSO₄, 0.25 (NH₄)₆Mo₇O₂₄, and 0.25 Fe-NaEDTA. This resulted in total concentrations of 8.75 mM N and 625 μM S. The experimental plants (high Al-P and low Al-P) were grown in the same peat medium amended with 2% by volume of P-charged alumina (P-Al₂O₃) (Lynch et al., 1990) and fertilized at each irrigation with the same nutrient solution as supplied to the control plants, but omitting the NH₄H₂PO₄ and using 380 μM (NH₄)₂SO₄, giving 7.38 mM N and 888 μM S. Thus, the only P source for the experimental treatments was from the P-Al₂O₃. Alumina was charged with two levels of P giving two levels of P desorption, 3.05 ± 0.2 μM P (low Al-P) and 9.26 ± 1.5 μM P (high Al-P) (Lynch et al., 1990). Plants were irrigated with distilled water after flowering (day 0).

Leachate was sampled once a week during each of the 3 weeks preceding flowering and at flowering and once more 3 weeks later. Leachate samples were collected from saucers beneath the pots immediately after irrigation. Four samples were collected at random from pots of each treatment on each preflowering sampling date and 12 samples were collected 3 weeks after flowering, one from each plant used for postproduction evaluation. Phosphorus content of leachate was analyzed using the phosphomolybdenum blue

method (Murphy and Riley, 1962). Phosphorus contents in preflowering leachate samples were not significantly different, so they were combined to give day 0 data.

QUALITY AND POSTPRODUCTION LONGEVITY. Plants on which two flowers had opened (day 0, representing initial flowering) were selected for postproduction analysis, and plant height and diameter were recorded. Six plants per treatment were placed in darkness at 16 to 17 °C for 4 d to simulate a transportation environment and then placed in a postproduction environment consisting of low light (8 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$) for 12 h·d⁻¹ and constant 21 to 23 °C. An additional six plants were placed directly in the postproduction environment.

Once a week after flowering, the height, width, and numbers of open flowers and wilted flowers were recorded for each plant. The experiment terminated 6 weeks after flowering for marigolds and 7 weeks after flowering for impatiens.

DROUGHT TREATMENT. Four weeks after anthesis, irrigation was withheld from six plants per treatment in the greenhouse until wilting of foliage was observed (2 to 4 d). Five plants were irrigated regularly as controls. After wilting of drought-stressed plants, the medium was rehydrated and the plants were allowed to recover completely (at least 2 d), as evidenced by full leaf turgor, before a second drought cycle was started. After two cycles of drought treatment, plant quality data were collected as described above. In addition, leaf area was recorded for control (undroughted) plants.

Midday leaf water vapor conductance was measured daily on the two youngest fully expanded leaves with a porometer (Delta-T Mk3; Cambridge, England).

STATISTICAL ANALYSIS. Data were analyzed using the PC-statistical package JMP (SAS Institute, 1989-91). The data collected weekly in the postproduction environment (number of flowers and percent wilted flowers) were analyzed by repeated measures analysis. Multiple comparisons were performed using ANOVA and mean separations with a paired student *t* test.

Results

The P levels in leachate from control plants decreased 7-fold during the 3 weeks after initial flowering (day 0), when the plants were irrigated with

Table 1. Phosphorus concentration and pH of leachate from conventionally fertilized (control) and alumina-buffered P-treated (high Al-P and low Al-P) plants before initial flowering (day 0) and after 3 weeks in the postproduction environment. During the postproduction period, plants were irrigated with distilled water only. Each value shown is a mean of 16 samples collected during 4 weeks preceding flowering (day 0) or 12 samples collected on one date 3 weeks after flowering (day 21) $\pm$ SE.

Treatment	Day 0		Day 21	
	[P] μ M	pH	[P] μ M	pH
Control	915 $\pm$ 305	4.5	133 $\pm$ 26	6.8
High Al-P	34.5 $\pm$ 9	4.5-5.0	16 $\pm$ 10	6.4
Low Al-P	6.1 $\pm$ 5	4.5-5.0	5.5 $\pm$ 1	6.5

Table 2. Time to bud break and plant height and diameter of impatiens and marigold plants grown at three P levels. Height and diameter were recorded when the second flower opened (day 0), which was the beginning of the postproduction period.

Species	P level	Budbreak (d)	Plant ht (cm)	Plant diam (cm)
Impatiens	Control	50.7 a ^z	11.5 a	33.8 a
	High Al-P	50.8 a	10.5 a	28.9 b
	Low Al-P	50.5 a	11.0 a	28.8 b
Marigold	Control	45.4 a	11.7 a	14.1 a
	High Al-P	46.0 a	11.5 a	15.1 a
	Low Al-P	46.2 a	11.7 a	14.0 a

^zNumbers within columns and species followed by the same letter are not significantly different according to the Student *t* test ($P < 0.05$).

Fig. 1 (above). Flower number of marigold and impatiens plants held in a postproduction environment. Plants were grown with conventional P fertilizer (control) or two concentrations of Al-buffered P. Phosphorus treatment significantly ($P < 0.01$) affected flower number for marigold, but had no significant effect on impatiens. Bars indicate SE.

Fig. 2 (below). Wilting of marigold and impatiens flowers in the postproduction environment. Plants were grown with conventional P fertilizer (control) or two concentrations of Al-buffered P. Phosphorus treatment significantly ($P < 0.01$) reduced flower wilting for both species. Bars indicate SE.

distilled water (Table 1). Phosphorus in the leachate from media amended with Al-P decreased $\approx$ 2-fold in the high Al-P pots and was constant in the low Al-P pots. The pH of the media increased over the experimental period in all treatments.

High levels of Al in the growth media can be toxic to roots, especially at low pH (de Lima and Copeland, 1994). However, there were no visible signs of damage due to the Al-P amendment in the growth media. The pH of the leachate ranged from 4.5 to 5 in all P treatments. In previous work, we found no accumulation of Al or symptoms of Al toxicity even in plants treated with much higher amounts of Al-P amendment at similar or lower pH (Lin, 1994; Lin et al., 1996).

QUALITY AND LONGEVITY. Impatiens plants fertilized with low and high Al-P were significantly more compact at flowering than control plants, evidenced by their smaller diameter compared with control plants (Table 2). Neither height nor diameter was affected by P treatment in marigold (Table 2). There was no difference among the treatments in time to bud break (Table 2).

There was no significant effect of simulated transportation (dark treatment) on postproduction quality (data not shown). The number of flowers developing in the postproduction environment was significantly increased by low Al-P treatment for marigold but

Fig. 3. Midday leaf water vapor conductance in irrigated and drought stressed marigold and impatiens plants grown under different P regimes. Drought was imposed by withholding irrigation until wilting, irrigating, and repeating the drought stress again after the plants had fully recovered. Data shown were recorded after 3 d of drought in the first cycle and after 2 (impatiens) or 3 (marigold) d of drought in the second cycle. Leaf water vapor conductance is also shown for irrigated plants on the same days. Bars indicate means of four (irrigated) or five (drought) replications $\pm$ SE. Pairs within panels labeled with the same letter are not significantly different ($P < 0.05$).

not for impatiens (Fig. 1). The rate of flower wilting was reduced by the Al-P treatments in marigold and impatiens (Fig. 2).

DROUGHT TOLERANCE. In irrigated plants, midday leaf water vapor conductance, an indicator of stomatal opening, varied during the experiment as the greenhouse conditions varied. However, there were no significant differences among P treatments for either marigold or impatiens plants (Fig. 3). Leaf area was reduced by low P treatments in undroughted plants of both species (Table 3).

When irrigation was withheld, plants grown with Al-P wilted more slowly than the control plants during

each of the drought cycles. Leaf water vapor conductance declined more slowly in Al-P-treated plants. For example, after 2 to 3 d of drought, when the conventionally fertilized plants were wilting and the Al-P plants were not, leaf water vapor conductance of Al-P plants was two to five times higher than conventionally fertilized plants (Fig. 3). The delayed decline in leaf water vapor conductance was observed in each of the two successive drought cycles (Fig. 3, compare left and right panels). Leaf water vapor conductance of conventionally fertilized plants was only 10% to 20% of that of corresponding irrigated plants (Fig. 3).

Roots were distributed uniformly in the pots amended with Al-P. The medium held together in a very compact root ball, which could be removed from the pot without falling apart. The root ball of control plants was small and insufficient to hold the medium together, and large areas of the pot contained no roots (Fig. 4).

Discussion

Use of Al-P as a media amendment has shown that plants grow well at P concentrations 100-fold lower than traditionally used in container plant production (Lin et al., 1996; Lynch et al., 1991). The solid-phase aluminum buffers phosphorus at a low but constant level, unlike fertigation with low P, which causes the P concentrations to fluctuate

with the irrigation cycles and with P depletion by root uptake.

In this experiment, impatiens plants grown with Al-P fertilization were more compact than plants grown at conventional, high P concentrations. Marigolds grown with Al-P had more flowers, which wilted more slowly in the postproduction environment, but compactness was not affected. There were no detrimental effects on plant quality from Al-P treatments for either species, even when the P concentration in the growth media was more than 100-fold lower than the control plants.

Impatiens and marigold plants grown with Al-P were more drought tolerant than plants grown with high P. The water status of the plants was reflected in the leaf water vapor conductance, a measure of the degree of stomatal opening. During each of two successive drought cycles, the Al-P plants closed stomates more slowly, indicating a lesser degree of water stress. Al-P plants had less leaf area than control plants, which could be responsible for reduced transpiration and water use.

Root architecture, proliferation, and mass affect the rate at which root systems remove moisture from soils (Faber et al., 1991). When P was supplied by amending the peat medium with $P-Al_2O_3$, the roots explored the medium uniformly. Marigold roots in pots fertilized with high-P solution (controls) tended to remain in a constricted area leaving large areas of the pot unexplored, which would allow proportionately more water to be lost by evaporation and reduce efficiency of water use (Furuta et al., 1977; Van de Werken, 1989). Although there were no obvious differences in root distribution in the media of high and Al-P impatiens plants, there could have been subtle differences in, for example, the distribution of fine roots. The volume of media explored could have been a factor contributing to

Table 3. Leaf area of undroughted impatiens and marigold plants 4 weeks after anthesis.

P level	Leaf area (cm ²)	
	Impatiens	Marigold
Control	1698 a	573 a
High Al-P	1094 b	274 b
Low Al-P	1285 ab	290 b

^aNumbers within columns and species followed by the same letter are not significantly different according to the Student *t* test ($P < 0.05$).

Fig. 4. Mature marigold plants grown with conventional P fertilizer (control) or two treatments with Al-P releasing P at $3.05 \pm 0.21 \mu\text{M}$ P (low Al) and $9.26 \pm 1.47 \mu\text{M}$ P (high Al). Note the uniform distribution of the roots in alumina-buffered P (high-Al and low-Al) plants.

water use efficiency in Al-P plants.

Use of buffered phosphorus fertilizer may provide bedding plant growers with a means to improve plant quality and stress tolerance while reducing fertilizer leaching and attendant waste-management problems. This research clearly shows that marigold and impatiens plants grown with lower concentrations of P provided by the buffered-P fertilizer have equal or better quality and improved tolerance to drought.

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The Effect of an Interdisciplinary Garden Program on the Environmental Attitudes of Elementary School Students

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ADDITIONAL INDEX WORDS. environmental education, children, gardening, outdoor activities, active learning

SUMMARY. Project GREEN (Garden Resources for Environmental Education Now) is a garden program designed to help teachers integrate environmental education into their classroom using a hands-on tool, the garden. The objectives of this research project were to 1) develop an interdisciplinary garden activity guide to help teachers integrate environmental education into their curricula and 2) evaluate whether children developed positive environmental attitudes by participating in the activities. Students participating in the Project GREEN garden program had more positive environmental attitude scores than those students who did not participate. Second-grade students in the experimental and control groups had more positive environmental attitudes than fourth-grade students. In addition, this research found a significant correlation between the number of outdoor related activities students had experienced and their environmental attitudes.

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