Root and Shoot Growth Responses to Phosphate Fertilization in Container-grown Plants

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ADDITIONAL INDEX WORDS. *Dypsis lutescens, Spathiphyllum, Ixora, Lycopersicon esculentum, Tagetes erecta, Capsicum annuum, Pentas lanceolata,* root to shoot ratio

SUMMARY. Areca palms [*Dypsis lutescens* (H. Wendl.) Beentje & J. Dransf.], spathiphyllums (*Spathiphyllum* Schott. 'Figaro'), ixoras (*Ixora* L. 'Nora Grant'), tomatoes (*Lycopersicon esculentum* Mill. 'Floramerica'), marigolds (*Tagetes erecta* L. 'Inca Gold'), bell peppers (*Capsicum annuum* L. 'Better Bell'), and pentas [*Pentas lanceolata* (Forssk.) Deflers. 'Cranberry'] were grown in a pine bark-based potting substrate and were fertilized weekly with 0, 8, 16, 32, or 64 mg (1.0 oz = 28,350 mg) of P per pot. Shoot, and to a much lesser extent, root dry weight, increased for all species as weekly P fertilization rate was increased from 0 to 8 mg/pot. As P fertilization was increased from 8 to 64 mg/pot, neither roots nor shoots of most species showed any additional growth in response to increased P. Root to shoot ratio decreased sharply as P fertilization rate was increased from 0 to 8 mg/pot, but remained relatively constant in response to further increases in P fertilization rate.

Among the nutrient elements required for plant growth, phosphorus has been associated with growth of meristem-

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Table 1. Planting and harvest dates for seven species of container-grown plants.

Species	Planting date	Harvest date
Areca palm	29 Mar. 1999	27 July 1999
Bell pepper	19 Apr. 1999	26 May 1999
Ixora	29 Mar. 1999	6 July 1999
Marigold	19 Apr. 1999	2 June 1999
Pentas	19 Apr. 1999	7 June 1999
Spathiphyllum	29 Mar. 1999	3 Aug. 1999
Tomato	29 Mar. 1999	26 Apr. 1999

atic tissue and in particular, root growth (Tisdale et al., 1985; Wittwer, 1969;). There is a widespread belief that P fertilization stimulates root growth over shoot growth. In a review on root to shoot ratios in trees, Harris (1992) cited seven examples of books or manuals on tree care that either stated or implied that P primarily promotes root growth and N shoot growth. However, none of these references provided any experimental data to support this dogma. The belief that P fertilization preferentially stimulates root growth over shoot growth has led to the practice of providing high P content starter fertilizers to promote rapid transplant establishment of horticultural plants (Wittwer, 1969), again without experimental evidence that high P fertilizers are beneficial to root growth. There is some evidence that P-starved roots grow and branch profusely when P is added to their environment (Drew and Saker, 1978), but nothing to indicate that roots of previously P-starved plants grow any faster than their shoots, or that addition of higher levels of P increases either root or shoot growth rates above that of minimally P-sufficient plants. Indeed, Anghinoni and Barber (1980) showed that P starvation, rather than its provision, increased root to shoot dry weight ratios in corn (*Zea mays* L.), and Dufault (1985) found that root to shoot ratios decreased with increasing P fertilization levels in celery [*Apium graveolens* var. *dulce* (Mill.) Pers.] transplants. Other studies showed that P had no effect on either root growth or root to shoot ratio in a wide range of plants (Dufault and Schultheis, 1994; Melton and Dufault, 1991; Weston and Zandstra, 1989; Yeager and Wright, 1981). The purpose of this study was to determine the root and shoot growth responses to P fertilization in a wide range of container-grown horticultural plants.

Materials and methods

Liners of areca palm, and plugs of 'Figaro' spathiphyllum, 'Nora Grant' ixora, 'Floramerica' tomato, 'Inca Gold' marigold, 'Better Bell' bell pepper, and 'Cranberry' pentas were transplanted into 3.8-L (1-gal) plastic containers using a 5 pine bark : 4 sedge peat : 1 sand (by volume) substrate amended with Micromax (Scotts Co, Marysville, Ohio) at 890 $g \cdot m^{-3}$ (1.5 lb / $yard^3$) and dolomitic limestone at 7.1 $kg \cdot m^{-3}$ (12 lb / $yard^3$). Ten replicate plants of each treatment were arranged in a completely randomized design within each species. Each pot received 50 ml (16.9 fl. oz) of a liquid fertilizer solution weekly containing 80 mg (0.0028 oz.) of both N and K from NH_4NO_3 and K_2SO_4 and 0, 8, 16, 32, or 64 mg of P from NaH_2PO_4.

Plants were grown in an open-sided greenhouse with a maximum PPFD of about 1800 $\mu E \cdot m^{-2} \cdot s^{-1}$ except for the spathiphyllums which were grown under shade (about 400 $\mu E \cdot m^{-2} \cdot s^{-1}$) within the same greenhouse. All pots received about 2 cm (0.8 inches) of water daily from overhead irrigation. All plants for a particular species were harvested when most of the plants reached a marketable size for a #1 container. Planting and harvest dates for each species are shown in Table 1. Shoots were cut off at soil level and roots were rinsed free of potting substrate before drying at 60 °C (140 °F) for dry weight determination. Data were analyzed by regression analysis using Table Curve 2D (SPSS, Chicago, Ill.) with the simplest models having the highest R^2 values and tightest confidence intervals being selected.

Results and discussion

Plants of all species were extremely stunted when grown with no supplemental P, and shoot dry weight increased sharply for all species as P applied per pot was increased from 0 to 8 mg / week (Figs. 1 and 2; Table 2). For most species, shoot dry weight showed little or no increase as P fertilization rate was increased from 8 to 64 mg / week. Shoot dry weight of bell peppers and areca palms appeared to decrease slightly as P fertilization rate was increased beyond 16 mg / week.

Root dry weight remained relatively constant for tomatoes and marigolds as P was increased from 0 to 64 mg / week (Fig. 1). However, bell peppers, pentas, ixoras, areca palms, and spathiphyllums showed a slight increase in root dry weight as P was increased from 0 to 8 mg / week (Figs. 1 and 2). For ixoras and spathiphyllums, root dry weight increased slightly at higher P fertilization rates, but areca palm root dry weight began to decrease at P fertilization rates of 16 mg / week or higher (Fig. 2).

Root to shoot ratios decreased with increasing P fertilization for tomatoes and marigolds (Fig. 1). Root to shoot ratio was highly variable for marigolds. For all other species, however, root to shoot ratios decreased sharply as P was increased from 0 to 8 mg / week, but remained relatively constant as P was further increased from 8 to 64 mg / week. These data demonstrate that

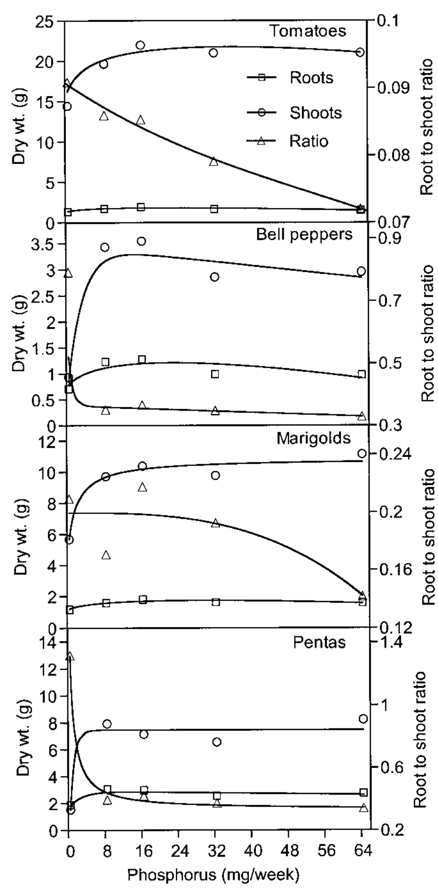

Fig. 1. Root and shoot growth responses to P fertilization in tomatoes, bell peppers, marigolds, and pentas. 28.35 g = 1.0 oz.

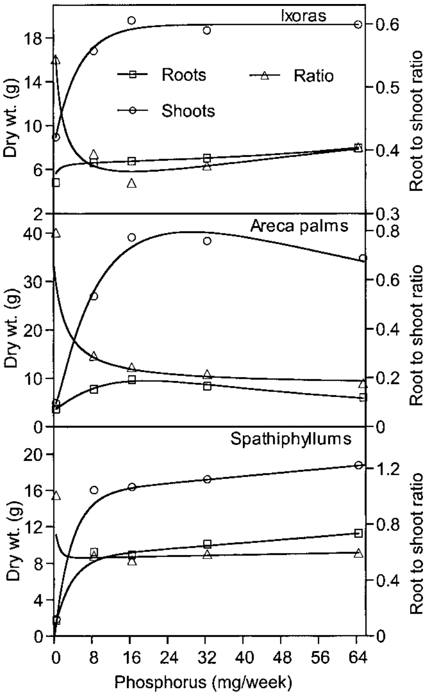

Fig. 2. Root and shoot growth responses to P fertilization in ixoras, areca palms, and spathiphyllums. 28.35 g = 1.0 oz.

increasing P fertilization rates does not promote root growth as popularly believed. In fact, only at deficiency levels of substrate P did roots of most species respond positively to increased P fertilization, and even then root response was less than that of the shoots. Higher levels of P resulted in little or no increase in root growth for these species. Similarly, shoot growth responded most dramatically to increasing P fertilization only at deficiency levels. Further additions of P generally did not result in additional shoot growth for most species and may even have suppressed shoot growth slightly at the highest levels (64 mg P / week) for areca palms and bell peppers. Root to shoot ratio, the best indicator of differential root growth response, decreased or remained the same as P fertilization rates were increased for all species tested. These results are in agreement with earlier studies on other crops (Anghinoni and Barber, 1980; Dufault, 1985; Dufault and Schultheis, 1999; Melton and Dufault, 1991; Weston and Zandstra, 1989; Yeager and Wright, 1981)

Conclusions

Our data suggest that most container-grown plants require only minimal amounts of P for optimum growth and that applications of high P fertilizers will not promote either root or shoot growth in plants as popularly believed. In fact, relative root growth actually decreased or stayed the same with increased P fertilization. Thus there is no advantage to using high P fertilizers in the production of these crops.

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Table 2. Regression equations for root, shoot, and root to shoot ratio responses to increasing P fertilization in seven species of container-grown plants.

Species	Response	Regression equation	R^2	F
Tomato	Roots	$y= 1.34–(2.58E–2)x + 0.22x^{0.5}$	0.867	6.49*
	Shoots	$y= 15.67–0.17x + 2.05x^{0.5}–1.24e^{–x}$	0.959	7.89**
	Ratio	$y= 9.06E–2–(4.83E–4)x + (4.9E–6)x^2–(2.99E–8)x^3$	0.989	31.28***
Bell pepper	Roots	$y= 0.74–(2.35E–2)x + 0.21x^{0.5}$	0.757	4.11*
	Shoots	$y= 3.51–(1.02E–2)x–2.57e^{–x}$	0.965	27.52***
	Ratio	$y=0.36–(5.41E–4)x + 0.43e^{–x}$	0.999	814.43***
Marigold	Roots	$y=1.17–0.02x + 0.21x^{0.5}$	0.890	8.13**
	Shoots	$y=5.67 + 1.56x^{–1}$	0.956	21.85***
	Ratio	$y=0.20–(2.16E–7)x^3$	0.660	5.64*
Pentas	Roots	$y=3.0–(5.64E–3)x + 1.11e^{–x}$	0.879	7.28*
	Shoots	$y=–(10.61E–x) + 7.466$	0.942	48.90***
	Ratio	$y=0.982x^{–1} + 0.33$	0.995	617.79***
Ixora	Roots	$y=6.24 + (2.78E–6)x^3 + 0.12x^{0.5}–1.4e^{–x}$	0.999	117,058.31***
	Shoots	$y=19.22–10.29E–(x / 5.05)$	0.987	77.32***
	Ratio	$y=0.69–0.21\ln x + (3.24E–2)(\ln x)^2+(6.3E–4)(\ln x)^3$	0.990	31.83***
Areca palm	Roots	$y=3.56–0.27x + (1.8E–6)x^3 + 2.44x^{0.5}$	0.956	24.95***
	Shoots	$y=4.39–x + 11.84x^{0.5}$	0.974	37.38***
	Ratio	$y=0.79 + 1.26x^{–1}$	0.999	1125.37***
Spathiphyllum	Roots	$y=8.69 + (4.04E–2)x–6.99e^{–x}$	0.996	249.49***
	Shoots	$y=15.62 + (4.9E–2)x–13.77e^{–x}$	0.999	74,079.09***
	Ratio	$y=0.56 + (6.13E–4)x + 0.45e^{–x}$	0.992	124.28***

*,**,***Significant at P = 0.05, 0.01, and 0.001, respectively.