Growth of *Pelargonium ×hortorum* and *Euphorbia pulcherrima* in Rubber-containing Substrates

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Abstract. Geranium (*Pelargonium ×hortorum* L.H. Bailey) 'Freckles' and poinsettia (*Euphorbia pulcherrima* Willd. ex Klotzch) 'Freedom' were grown in six peat and shredded-rubber substrates formulated to contain 75:25:0, 50:50:0, 25:75:0, 75:0:25, 50:0:50, 25:0:75 sphagnum peat : fine-grade rubber : coarse-grade rubber (by volume). Additionally, plants were grown in a 50 peat : 30 perlite : 20 loam (by volume) control substrate. Shredded rubber-containing substrates had higher bulk densities, lower total pore space, and higher total solids than the control substrate. Fine rubber-containing substrates had lower air-filled pore space (AFP) and lower water-holding capacities (WHC) than the control substrate. Substrates containing 25% coarse rubber had lower AFP and WHC than the control, but substrates containing 50% and 75% coarse shredded rubber had higher AFP and lower WHC than the control. Shredded rubber-containing substrates had significantly higher levels of Zn than the control substrate. Plants grown in rubber-containing substrates had tissue Zn levels significantly higher than the control and at levels reported to be phytotoxic in other species. Geraniums grown in rubber-containing substrates had lower root and shoot fresh mass, were shorter, and had fewer axillary branches than those grown in the control substrate. Poinsettia plants grown in rubber-containing substrates were shorter, had lower shoot fresh mass, fewer bracts, and lower bract area as compared to plants grown in the control substrate.

Substrates composed of materials such as peat moss (peat), bark, perlite, styrofoam, vermiculite, sand, rock wool, or natural field soils are typically utilized in greenhouse production of containerized crops (Bunt, 1988; Nelson, 1991). Significant interest exists in developing alternative substrate components that have improved physical and chemical properties or a lower cost. Many of the materials tested have either been agricultural or municipal waste products. Rubber from shredded waste tires is one material that has generated interest as an alternative material for use in horticultural substrates. The motivation for using shredded tires as a substrate component comes not only from the desire of the horticultural industry for alternative substrate materials, but also from the need to utilize the 242 million tires discarded annually (Riggle, 1992).

Most research on the use of shredded rubber in horticulture has focused on its incorporation into the soil of recreational turf surfaces to improve impact resistance and reduce the

harm of surface traffic (Lehnert, 1982; Rogers et al., 1994). Limited research has been conducted on the use of shredded rubber as a substrate component for greenhouse crop production. Harkess et al. (1995) found that incorporating shredded rubber into bark-based substrates had no significant effect on days to emergence, height, number of florets, scape length, or stem length in *Gladiolus ×hortulanus* L.H. Bailey 'Wig's Sensation'. However, harvest date was significantly delayed in the 50% shredded rubber : 25% peat : 25% sand (by volume) substrate. Zhao (1995) reported that *Salvia splendens* F. Sellow ex Roem. & Schult. 'Red Hot Sally' and *Catharanthus roseus* (L.) G. Don. 'Cooler Peppermint' could be grown in substrates containing 25% shredded rubber without a significant reduction in growth as compared to plants grown in substrates without shredded rubber. However, *Exacum affine* Balf. 'Little Champ', *Catharanthus roseus* 'Cooler Grape', *Tagetes erecta* L. 'Discovery Yellow', and *Begonia semperflorens* Hort. 'Vodka' plants grew less in substrates containing 25% shredded rubber than in the controls. Bowman et al. (1994) reported that *Dendranthema ×grandiflorum* (Ramat.) Kitamura 'Bright Golden Anne' (chrysanthemum) plants grown in rubber-containing substrates had reduced height, fresh and dry mass, and fewer open flowers as compared to a control substrate of 1 sand : 2 sawdust (v/v). Further, chrysanthemum plants grown in rubber-containing substrates had lower tissue lev-

els of N, P, K, Ca, Mg, and Cu than plants grown in substrates without rubber.

The objective of this research was to compare the growth of *Pelargonium ×hortorum* (geranium) and *Euphorbia pulcherrima* 'Freedom Red' (poinsettia) in substrates containing various grades and proportions of shredded rubber.

Materials and Methods

Prior to formulation of substrates, dolomitic limestone was added ($4.15 \text{ kg} \cdot \text{m}^{-3}$) to sphagnum peat (peat) and pasteurized at 60°C for 30 min. The peat was allowed to incubate at 20°C for 10 d before use, at which time the pH was 5.1. Peat was formulated with either a fine- or coarse-grade shredded rubber (Rouse Rubber Industries, Vicksburg, Miss.). For fine grade, 99% of the particles were between 2.0 and 0.25 mm, and for the coarse grade, 89% of the particles were between 8.0 and 2.0 mm (Fig. 1). Six peat and shredded-rubber substrates were formulated to contain 75:25:0, 50:50:0, 25:75:0, 75:0:25, 50:0:50, 25:0:75 sphagnum peat : fine-grade rubber : coarse-grade rubber (by volume). In addition to these substrates, a substrate of 50 peat : 30 perlite : 20 loam (by volume) was included as a control.

Particle size distribution was determined by sieving 100-g samples on a CSC Scientific (Fairfax, Va.) rotary shaker for 10 min using screens with pore diameters of 8.0, 6.3, 4.0, 2.0, 1.0, 0.5, and 0.25 mm. Five samples were screened for each grade of rubber and material collected in each screen was weighed. Mass and standard errors were plotted against pore size.

The physical properties of the substrates were determined before planting. The air-filled pore space at container capacity (% by volume), water-filled pore space at container capacity (% by volume), total pore space (% by volume), total solids (% by volume), water-holding capacity at container capacity (% by mass), and bulk density ($\text{g} \cdot \text{cm}^{-3}$) were determined using loose-packed cores and methods adapted from Byrne and Carty (1989). However, we used 7.5-cm (height) $\times$ 7.5-cm (inside diameter) cylinders with volumes of 345 mL.

Chemical properties of substrates and tissue analysis were conducted by the Mississippi State Univ. Soil and Plant Analysis Laboratory at the termination of the experiment. The electrical conductivities (measured as $\text{mS} \cdot \text{cm}^{-1}$) of the substrate solutions were determined using a YSI Scientific model 35 conductance meter (Yellow Springs Instrument Co., Yellow Springs, Ohio), and the pH was determined using an Orion model 920A meter (Orion Research, Boston). Substrate ammonium and nitrate nitrogen concentrations were determined using an Orion model 95-12 electrode. P, K, Ca, Mg, Na, and Zn concentrations were determined on the filtered extract by simultaneous, inductively coupled argon-plasma emission spectrometry (Jones, 1977; Munter and Grande, 1981). Elemental analysis of plant tissue (Isaac and Johnson, 1975; Jones and Steyn, 1973; Nelson and Sommers,

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Figure 1. Particle size distribution and standard errors for fine and coarse grades of shredded rubber. Means are for five replications.

1972) was conducted using fully expanded leaves. Because of sample limitations, substrate and tissue tests were pooled across rubber proportion in the substrate. Five replications were tested for each substrate and tissue treatment.

'Freckles' geranium seed were sown in flats (52 × 26 × 3 cm) filled with a 50 peat : 30 perlite : 20 loam (% by volume) substrate amended with dolomitic limestone to a pH of 5.5. After 10 d, seedlings were transplanted into plug trays (#273 with 5 mL volume) filled with the same substrate used for germination. After an additional 14 d, plugs were planted into 10-cm (640 mL) containers filled with the respective experimental substrates.

Rooted poinsettia 'Freedom Red' plants were potted into 15-cm containers (1700 mL) filled with the experimental substrates. Plants were maintained under long days using a night interruption from 22:00 to 02:00 HR using incandescent bulbs supplying 5 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ photosynthetic photon flux (Li-185-A quantum sensor; LI-COR, Lincoln, Neb.). After 14 d, plants were decapitated to six nodes, and after an additional 21 d, plants were placed under naturally occurring short days.

The slow-release fertilizer Sierra 17N-2.6P-10K with microelements (Scotts, Marysville, Ohio) was incorporated into the substrates at a rate of 5 g per container. An application of microelements was made by applying Soluble Trace Element Mix (W.R. Grace, Fogelsville, Pa.) at 0.2g·L⁻¹ and 100 mL per container 7 d after planting. Additional Mg was supplied to poinsettias by the application of MgSO₄ at 0.6 g·L⁻¹ and 100 mL per container at 30-d intervals.

Plants were grown in a glass greenhouse. Ambient light levels averaged 650 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$, at 12:00 HR at the initiation of the experiment, and the temperatures ranged

from 19 to 30 °C. Water was supplied using drip tube irrigation supplying 120 and 240 mL daily for geranium and poinsettia, respectively.

Days to anthesis, shoot fresh mass, and plant heights were recorded for both species. Root fresh mass was recorded for geranium. The design was completely randomized with seven replications of each treatment. An analysis of variance was conducted to determine if substrate significantly affected substrate properties or plant growth. Single degree-of-freedom contrasts were performed to determine significant differences between proportions and grades of rubber and between rubber-containing substrates and the control. In the case of physical properties and plant growth responses, a least significant difference (LSD) mean separation test ($\alpha = 0.05$) was conducted to allow for comparisons within a grade of rubber.

Results

Substrates. Although substrates containing 25% coarse or fine rubber had similar air-filled pore space (AFP), substrates containing 50% or 75% coarse rubber had significantly more AFP than those containing 50% or 75% fine rubber (Table 1). Overall, AFP was lower in substrates containing fine rather than coarse rubber. The proportion of fine rubber in the substrate had no significant effect on the AFP, but as the proportion of coarse rubber increased, the AFP of the substrate increased. Overall, substrates containing rubber had similar AFP to the control.

Although substrates containing 25% coarse or fine rubber had similar water-filled pore space (WFP), substrates containing 50% and 75% coarse rubber had significantly lower WFP than those containing 50% and 75% fine rubber (Table 1). Overall, WFP was lower in

substrates containing coarse rubber than those containing fine rubber. The proportion of fine rubber in the substrate had no significant effect on the WFP, but as the proportion of coarse rubber increased, the WFP of the substrate decreased. Overall, substrates containing rubber had similar WFP to the control.

Water-holding capacity (WHC) was similar for substrates containing either 25% or 50% coarse or fine rubber (Table 1). Substrates containing 75% coarse rubber had a significantly lower WHC than substrates containing 75% fine rubber. As the proportion of coarse rubber in the substrate increased, the WHC decreased. The proportion of fine rubber did not significantly affect the WHC. Overall, WHC was similar for substrates containing coarse or fine rubber, while rubber-containing substrates had a significantly lower WHC than the control substrate.

Although the proportion of fine rubber did not significantly affect the bulk density (BD), it increased as the proportion of coarse rubber in the substrate increased (Table 1). There were no significant differences between coarse and fine rubber. All rubber-containing substrates had significantly higher BD than the control.

The total pore space (TPS) and total solids (TS) were similar for coarse and fine rubber-containing substrates (Table 1). The proportion of fine rubber did not significantly affect TPS or TS, but as the proportion of coarse rubber increased, the TPS significantly decreased and TS significantly increased. Overall, TPS was significantly lower for the rubber-containing substrates and the TS was significantly higher for them than for the control.

The pH was significantly higher in substrates containing fine rubber than substrates containing coarse rubber, and rubber-containing substrates had a higher pH than the control substrate (Table 2). Fine rubber-containing substrates had a lower electrical conductivity (EC) than the coarse rubber-containing substrates. The EC was significantly lower in the rubber-containing substrates than in the control. Fine rubber-containing substrates had significantly lower concentrations of NO₃⁻, NH₄⁺, P, and K than those containing coarse rubber. Overall, NO₃⁻, NH₄⁺, P, and K concentrations were similar for rubber-containing substrates and the control. Rubber-containing substrates had significantly lower levels of Ca than the control, but Ca levels were similar for fine rubber- and coarse rubber-containing substrates. Fine rubber substrates had lower Mg and Na levels than coarse rubber substrates, and overall, rubber-containing substrates had lower levels of Mg and Na than the control. Both fine and coarse rubber-containing substrates had significantly higher Zn levels than the control, and the fine rubber-containing substrates had higher Zn levels than those containing coarse rubber.

Plant Growth. Geranium tissue N, P, K, Ca, and Mg concentrations were similar for substrates and the respective ranges were 34 to 46, 3, 16 to 20, 9 to 15, and 5 to 6 g·kg⁻¹ DM. Geranium tissue Fe, Mn, and Cu concentrations were also similar and ranges were 130 to

Table 1. Physical properties of rubber-containing substrates used to produce geranium and poinsettia.

Substrate (peat : fine : coarse) ^z	Air-filled pore space (% v/v)	Water-filled pore space (% v/v)	Water-holding capacity (% m/m)	Bulk density (g·cm ⁻³)	Total pore space (% v/v)	Total solids (% v/v)
75:25:0	3.3	62.0	212	0.32	65.3	34.7
50:50:0	2.9	59.8	170	0.36	62.7	37.3
25:75:0	2.9	54.4	147	0.41	57.4	42.6
75:0:25	4.2	63.5	252	0.26	67.7	32.3
50:0:50	12.1	46.9	120	0.39	59.0	41.0
25:0:75	21.3	28.7	59	0.49	49.9	50.0
Control	9.0	67.6	481	0.14	76.7	23.3
Significance	df					
Treatment	6	***	***	***	***	**
25 vs. 25 ^y	1	NS	NS	NS	NS	NS
50 vs. 50	1	***	*	NS	NS	NS
75 vs. 75	1	***	***	*	NS	NS
Coarse vs. fine	1	***	***	NS	NS	NS
Rubber vs. control	1	NS	**	***	***	***
LSD ($\alpha = 0.05$)	14	3.6	10.8	93.1	0.11	10.8

^zPeat indicates sphagnum peat, fine indicates fine-grade shredded rubber, and coarse indicates coarse-grade shredded rubber. Control indicates Iowa State Univ. greenhouse standard mix, composed of 50 sphagnum peat : 30 perlite : 20 loam (by volume). Means are for five replications.

^yRefers to the proportion of fine and coarse rubber, respectively.

NS, *, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

Table 2. Substrate analysis of rubber-containing substrates.^z

Component	pH	EC	NO ₃ ⁻	NH ₄ ⁺	P	K	Ca	Mg	Na	Zn
Fine ^y	6.2	0.4	19	5	68	93	810	49	42	147
Coarse	5.3	1.4	190	87	141	344	957	262	95	72
Control	5.0	2.0	261	84	138	367	2084	447	158	8
Significance	df									
Treatment	2	*	***	*	*	***	**	***	***	**
Fine vs. coarse	1	*	***	*	*	***	NS	***	**	**
Rubber vs. control	1	*	***	NS	NS	NS	***	***	***	**

^zEC reported as mS·cm⁻¹ and NO₃⁻, NH₄⁺, P, K, Ca, Mg, Na, and Zn reported as mg·kg⁻¹. Means are for five replications.

^yFine indicates fine-grade shredded rubber and coarse indicates coarse-grade shredded rubber. For rubber-containing substrates, samples were pooled across proportion of rubber in the substrate. Control indicates Iowa State Univ. greenhouse standard mix, composed of 50 sphagnum peat: 30 perlite: 20 loam. Means are for five replications.

NS, *, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

Table 3. Growth of geranium in rubber-containing substrates.

Substrate (peat : fine : coarse) ^z	Fresh mass		Height (cm)	Axillary shoots (no.)	Inflor- escences (no.)	Days to flower
	Root (g)	Shoot (g)				
75:25:0	9.1	21.5	11.7	20.2	0	---
50:50:0	6.8	20.0	11.1	17.6	0	---
25:75:0	5.1	11.0	10.4	10.8	0	---
75:0:25	21.4	47.2	16.3	20.4	0.3	82.0
50:0:50	11.2	32.4	13.8	15.2	0	---
25:0:75	6.6	22.2	10.3	13.3	0	---
Control	21.4	92.5	20.4	28.4	0.9	78.0
Significance	df					
Treatment	6	***	***	***	***	NS
25 vs. 25 ^y	1	**	***	***	NS	---
50 vs. 50	1	NS	NS	NS	NS	---
75 vs. 75	1	NS	NS	NS	NS	---
Coarse vs. fine	1	**	***	**	NS	---
Rubber vs. control	1	***	***	***	***	---
LSD ($\alpha = 0.05$)	14	4.3	10.1	4.8	0.2	---

^zPeat indicates sphagnum peat, fine indicates fine-grade shredded rubber, and coarse indicates coarse-grade shredded rubber. Control indicates Iowa State Univ. greenhouse standard mix, composed of 50 sphagnum peat : 30 perlite : 20 loam (by volume). Means are for seven replications.

^yRefers to the proportion of fine and coarse rubber, respectively.

NS, *, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

210, 163 to 239, and 5.3 to 7.7 mg·kg⁻¹ DM. At 387 mg·kg⁻¹ DM, tissue from geraniums grown in fine rubber-containing substrates had significantly higher Zn concentrations than that from coarse rubber-containing substrates and the control, which had 149 and 23 mg·kg⁻¹ DM, respectively. Overall, geranium tissue from rubber-containing substrates had signifi-

cantly higher levels of Zn than the control.

Root (RFM) and shoot fresh mass (SFM) were lower and plants were shorter when grown in 25% fine rubber as compared to plants grown in 25% coarse rubber (Table 3). Plants grown in 50% or 75% fine rubber and 50% or 75% coarse rubber had similar RFM, SFM, and heights. Overall, plants grown in

fine rubber-containing substrates had significantly reduced RFM, SFM, and heights. For coarse rubber-containing substrates, the higher the proportion of rubber in the substrate, the lower the root and shoot fresh mass and heights. The proportion of fine rubber in the substrate did not significantly affect the RFM, SFM, or height. As compared to plants grown in control substrates, plants grown in rubber-containing substrates had significantly lower RFW, SFM, and heights. The number of axillary shoots were similar among the rubber-containing substrates. However, plants grown in rubber-containing substrates had significantly fewer axillary shoots than plants grown in the control substrate.

At the termination of the experiment, only plants in the control substrate and the 25% coarse rubber-containing substrate had flowered (Table 3). The number of inflorescences per plant was significantly lower in the 25% coarse rubber-containing substrate than for the control substrate, and, overall, there were fewer inflorescences for plants grown in rubber-containing substrates than for plants grown in the control substrate. Because plants of only two treatments flowered by the termination of the experiment, contrasts were omitted for days to flower.

Days to anthesis in poinsettia were similar for all substrates and ranged from 54 to 57 d. Plants were significantly taller in the 25% coarse rubber-containing substrate than in the 25% fine rubber-containing substrate (Table 4). However, plants were taller when grown in 50% and 75% fine rubber as compared to the 50% and 75% coarse rubber-containing substrates. Overall, plants grown in fine rubber-containing substrates were taller as compared to plants grown in coarse rubber-containing substrates. For both fine and coarse rubber-containing substrates, plants were shorter as the proportion of rubber increased. Overall, plants grown in rubber-containing substrates had reduced heights as compared to plants grown in the control substrate.

There were no significant differences in the number of axillary shoots among plants grown in rubber-containing substrates (Table

Table 4. Growth of poinsettia in rubber-containing substrates.

Substrate (peat : fine : coarse) ^a	Ht (cm)	Axillary shoots (no.)	Shoot fresh mass (g)	Bracts (no.)	Bract area (cm ²)
75:25:0	28	5	95	51	2364
50:50:0	29	5	73	43	2021
25:75:0	25	5	51	39	1559
75:0:25	32	5	102	55	2725
50:0:50	23	4	40	32	1180
25:0:75	21	4	28	25	890
Control	30	5	122	62	3345
Significance	df				
Treatment	6	***	***	***	***
25 vs. 25 ^y	1	**	NS	NS	NS
50 vs. 50	1	***	NS	*	**
75 vs. 75	1	**	NS	*	*
Coarse vs. fine	1	**	NS	*	*
Rubber vs. control	1	***	***	***	***
LSD ($\alpha = 0.05$)	14	2.6	0.9	14.2	9.7

^aPeat indicates sphagnum peat, fine indicates fine-grade shredded rubber and coarse indicates coarse-grade shredded rubber. Control indicates Iowa State Univ. greenhouse standard mix composed of 50 sphagnum peat : 30 perlite : 20 loam (by volume). Means are for seven replications.

^yRefers to the proportion of fine and coarse rubber, respectively.

NS, *, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

4). However, the number of axillary shoots was significantly reduced for plants grown in rubber-containing substrates as compared to plants grown in the control substrate.

SFM, number of bracts (NB), and bract area (BA) were similar for plants grown in 25% fine rubber- and 25% coarse rubber-containing substrates. Plants grown in 50% and 75% coarse rubber-containing substrates had lower SFM, had fewer bracts, and had less bract area than plants grown in 50% and 75% fine rubber-containing substrates. As the proportion of rubber increased, the SFM, NB, and BA decreased. Overall, plants grown in coarse rubber-containing substrates had lower SFM, had fewer bracts, and had less BA than plants grown in fine rubber-containing substrates, and plants grown in rubber-containing substrates had lower SFM, had fewer bracts, and had less BA than plants grown in the control.

Discussion

Reduced growth in geranium and poinsettia, relative to the controls, may be a result of several factors. The AFP of all fine rubber substrates and of the 25% coarse rubber substrate were significantly lower than for the control, as well as being below the recommended range of 5% for geranium and 5% to 10% for poinsettia (Bunt, 1988). The suboptimal AFP may have contributed to reduced growth in plants grown in those substrates, but cannot account for the reduced growth in the 50% and 75% coarse rubber substrates, which had significantly higher AFP than the control.

WHC was lower in rubber-containing substrates and decreased as the proportion of rubber increased. Because plants were watered once per day rather than as needed, plants grown in these substrates may have suffered water stress during the study, resulting in reduced growth.

The chemical properties of the substrates varied significantly with rubber-containing substrates, generally having lower concentra-

tions of mineral elements. The exception was Zn levels, which were significantly higher in rubber-containing substrates. Shredded rubber used in this study was reported by the supplier (Rouse Rubber Industries) to contain Zn at 13,000 mg·kg⁻¹. Fine-rubber substrates contained higher Zn levels than the coarse rubber substrates. The reduced growth of geranium and poinsettia may have been due to Zn toxicity. The substrate Zn levels we reported were significantly higher than those demonstrated to cause Zn toxicity in other crops (Davies, 1993; Earley, 1943; Lee et al., 1992; Ren et al., 1993), and Zn tissue levels were higher than those reported to cause Zn toxicity (Carsky and Reid, 1990; Davis and Parker, 1993; Ruano et al., 1987). Further, many of the geranium plants grown in rubber substrates exhibited interveinal chlorosis, which is one of the reported symptoms of Zn toxicity (Gupton, 1996; Milbocker, 1974; Ren, 1993). Interveinal chlorosis was absent on poinsettia.

Our results are similar to those of Milbocker (1974), who reported reduced growth in *Ilex crenata* Thunb. and *Zea mays* L. when grown in substrates composed of sphagnum peat and shredded rubber. The levels of Zn in the substrate and in the plant tissues increased with increasing amounts of rubber in the substrate, and the growth of these species was inversely correlated to the amount of rubber in the substrate.

Our results are also similar to those of Bowman et al. (1994), who reported that *Dendranthema × grandiflorum* 'Bright Golden Anne' plants grown in rubber-containing substrates were shorter, had lower fresh mass, lower dry mass, and fewer open flowers as compared to a control substrate of 1 sand : 2 sawdust (v/v). However, Bowman et al. (1994) reported lower tissue levels of N, P, K, Ca, Mg, and Cu for plants grown in rubber-containing substrates than in plants grown in substrates without rubber. Only tissue Zn levels were significantly different between rubber-

containing substrates and the control in our study.

While previous research has shown acceptable growth of several species in substrates containing as high as 25% shredded rubber, our research demonstrated that geranium and poinsettia growth was reduced in substrates containing shredded rubber as compared to a peat : perlite : loam substrate.

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