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Growth and Nutrition of Geraniums Grown in Media Developed From Waste Tire Components

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Abstract. **Two cultivars of zonal geraniums (*Pelargonium ×hortorum* Bailey), 'Danielle' and 'Kim', were grown in media containing three grind sizes of rubber (2.4, 6, or 10 mm) and fiber from the fabric belting processed from waste tires in three proportions: 1 rubber or fiber : 1 peat; 1 rubber or fiber : 1 vermiculite : 2 peat; and 2 rubber or fiber : 1 vermiculite : 1 peat (by volume). Two control media were also included: 1 vermiculite : 1 peat, and 1 rockwool : 1 peat (by volume). Geranium plants were grown in media containing up to 25% waste tire products along with traditional medium components without reducing plant quality. Plant growth was best and flower count was highest in the vermiculite and peat medium, plants were smallest and flower count was lowest in media containing the rubber grinds at 2.4 or 6 mm, making up 50% of the media. The medium 1 rubber : 1 vermiculite : 2 peat, regardless of grind or fiber, produced plants equal to the rockwool and peat moss medium. All plants grown in media containing rubber by-products had elevated Zn and Cu in the foliage; however, Zn and Cu were highest in media containing 50% rubber. Foliar P : Zn ratios were less for plants grown in media containing 50% rubber and also were lower in plants grown in media with smaller rubber grind sizes.**

More than 242 million rubber tires are discarded annually in the United States (Riggle, 1992). Less than 7% are currently being recycled, while 16% are used for their fuel value or are exported. Most of the remaining tires are either stockpiled or added to landfills, even though costs for solid waste disposal have increased (Lytton, 1991). Waste tire rubber has been used a medium amendment for soybean (*Glycine max* Merr.). Five percent tire rubber added to a loam soil improved soil tilth over loam alone, and yield was not influenced (C.Y. Ward, unpublished data). The soil on a football field amended with 20% tire rubber had reduced compaction, and the turf had increased shear resistance (Rogers et al., 1994). Bermudagrass (*Cynodon dactylon* L.) grown in soil amended with rubber had lower total dry matter and showed some phytotoxic symptoms (C.Y. Ward, unpublished data). The phytotoxicity was attributed to available zinc found in the rubber. Marketable chrysanthemum [*Dendranthema ×grandiflora* (Ramat.) Kitamura] plants were grown in media containing rubber (Bowman et al., 1994), although Zn levels were elevated in the foliage.

To date, studies using waste tires as a medium have used only the rubber fraction. A recycler obtains three products from processing a waste tire: steel from the bead and belting, fabric fibers from the belting and sidewalls, and rubber. The steel is separated and sold as scrap while the rubber is processed for many uses, including incorporation in asphalt, athletic surfaces, and landscape amendments. Fabric fibers from waste tires to date have no economic benefit. The objectives of this study were to determine the feasibility of the use of rubber and fiber from the processing of waste tires as a growing medium for geranium.

Materials and Methods

Three grind sizes of rubber, 2.4, 6, and 10 mm, and fiber processed from waste tires were obtained from a local waste tire processor (JaiTire, Denver). These four waste tire products were blended individually with Michigan peat (Michigan Peat Co., Houston) into three root-zone media by volume: 1 rubber or fiber : 1 peat; 1 rubber or fiber : 1 vermiculite : 2 peat; and 2 rubber or fiber : 1 vermiculite : 1 peat. Two control media were also blended by volume: 1 vermiculite : 1 peat; and 1 rockwool (Par-gro, medium grade rockwool; Partek Insulation, Co., Brunswick, Ohio) : 1 peat. All media were amended with dolomitic limestone at 6 $kg·m^{-3}$. Rooted cuttings of two cultivars of zonal geraniums, 'Danielle' and 'Kim', were transplanted 3 Mar. 1995 into 500-mL (13 cm) round plastic azalea pots containing each medium combination. The study was conducted in a fiberglass-covered greenhouse. Plants were fertigated, as needed, using 20N–2.2P–8.3K (20–10–20 Masterblend: Vaughan Products, Chicago) initially with N at 200 $mg·L^{-1}$ then increased to 250 $mg·L^{-1}$ after 4 weeks until study termination. A wetting agent (AquaGro 2000 L; Aquatrols, Cherry Hill, N.J.) was applied to the media as a drench at 5 $mL·L^{-1}$. The average day time air maximum was 23 ± 0.6 °C and the night minimum was 16.5 ± 0.4 °C for the entire study, which was terminated 2 May 1995.

There were 10 pots per treatment combination with one plant per pot. All plants were used to determine plant height, width, and flower count. Five randomly selected plants for each cultivar and treatment combination were subsequently dried at 70 °C for 48 h for determining dry mass and foliar analysis. Leaves were separated from stems, dried, ground to pass a 0.25-mm screen (60 mesh), and digested according to the method of Sah and Miller (1992) using closed vessel microwave digestion. Elemental composition was determined using inductively coupled plasma atomic emission spectrophotometry (ICP-AES) (Atom Scan 25; Thermo Jarrell-Ash Corp., Franklin, Mass.). Analyses of variance were conducted as completely randomized 2 × 3 × 4 factorial designs having two cultivars, three formulations, and four rubber products. The two control media were included into the model and mean separations were conducted using Fisher's protected least significant difference procedure (LSD) with 95% confidence level.

Samples of each medium were collected at the initiation, middle, and termination of the study. The media were analyzed by NH_4HCO_3 diethylene-triaminepentaacetic acid (DTPA) extract according to Soltanpour and Schwab (1977) with subsequent analysis of P, Zn, and Cu using ICP-AES (model 61; Thermo Jarrell-Ash Corp.). Nitrate-N was detected spectrophotometrically by an automated flow injection analyzer (Lachat Instruments, Milwaukee, Wis.). Results were pooled within rubber products.

Results and Discussion

'Kim' was taller and had more mass and flowers than 'Danielle' (Table 1), but no interactions were detected between the cultivars and media (Table 2); therefore, the cultivar results were pooled for further analysis. Gera-

Table 1. Flower count, plant height, and dry mass of *Pelargonium ×hortorum* 'Danielle' and 'Kim'.

	Plant characteristic		
Cultivar	Flower count	Ht (cm)	Dry mass (g)
Danielle	3.4	13.4	14.2
Kim	5.1	14.4	16.0
Significance	****	****	****

****Significant at $P \leq 0.001$.

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nium plants were grown in media containing 25% rubber waste products with marketable plant quality. Plants grown in 1 vermiculite : 1 peat medium were taller, heavier, and had more flowers than plants grown in media containing 50% rubber of 2.4- and 6-mm particle size (1 rubber : 1 peat and 2 rubber : 1 vermiculite : 1 peat) (Table 3). Plants grown in 1 rubber : 1 vermiculite : 2 peat medium, regardless of grind or fiber, were equal in size and had similar flower counts to those in the 1 rockwool : 1 peat control medium. Similar results have been demonstrated with chrysanthemum (Bowman et al., 1994) and *Exacum affine* Balf.f. (Zhao, 1995).

All plants grown in media containing rubber by-products had elevated levels of Zn in the foliage (Table 4). The Zn level for most plants grown in media containing rubber exceeded 200 $mg\cdot kg^{-1}$. The highest levels of foliar Zn were found in plants grown in media containing 50% rubber or fiber. Foliar levels of Zn have been previously shown to be high in plants grown in waste rubber products (Bowman et al., 1994; Zhao, 1995). Adequate levels of foliar Zn for most crops is from 40 to 200 $mg\cdot kg^{-1}$ (Jones et al., 1991). We attribute the large amount of available Zn in the media to the inherently high levels of Zn in the rubber. Zinc dimethyldithiocarbamate or zinc isopropylxanthate is used as an accelerator to reduce the time needed for vulcanization of rubber (Roff et al., 1971).

The pH values of the control media during the study were 5.1, 6.8, and 6.6, initial, middle, and terminal, respectively, with electrical conductivity (EC) values 0.4, 0.5, and 1.5 $dS\cdot m^{-1}$, respectively. Neither grind size nor percentage of rubber in the media affected the pH or the EC (data not shown). The pH values of the rubber and fiber media during the study were 5.9, 6.5, and 6.3, initial, middle and terminal, respectively, and EC values were 0.2, 0.2, and 1.1 $dS\cdot m^{-1}$, respectively. The levels of extractable Zn increased over the duration of the

Table 2. Analysis of variance for *Pelargonium ×hortorum* 'Danielle' and 'Kim' plant characteristics and foliar analysis. Plants were grown in media containing multiple grind size rubber products from waste tires.

	Dependent variable						
	Plant characteristic			Element			
Source of variation	Flower count	Ht	Dry mass	P	Zn	P : Zn ratio	Cu
Medium	****	****	****	***	****	***	***
Grind size	*	*	****	NS	****	****	****
Medium × grind size	NS	*	***	NS	**	NS	NS
Cultivar	****	****	****	****	NS	***	**
Medium × cultivar	NS	NS	NS	NS	NS	NS	NS
Grind size × cultivar	NS	NS	NS	NS	NS	***	***
Medium × grind size × cultivar	NS	NS	NS	NS	NS	NS	NS

NS, *, **, ***, ****Nonsignificant or significant at $P \leq 0.05$, 0.01, 0.001, or 0.0001, respectively

Table 3. Plant characteristics of *Pelargonium ×hortorum* Bailey grown in media containing various sizes of rubber products and grinds from waste tires.

		Plant characteristics		
Component	Particle size or type (mm)	Flower no.	Plant Ht (cm)	Dry mass (g)
1 Rubber : 1 peat (by volume)	2.4	2.8 e[z]	12.1 e	8.6 f
	6	3.8 cd	12.6 de	12.6 e
	10	3.4 de	13.9 c	13.8 e
	Fiber	3.3 e	13.6 c	13.8 e
1 Rubber: 1 vermiculite : 2 peat (by volume)	2.4	4.2 a–c	14.5 bc	18.4 bc
	6	4.2 a–c	14.5 bc	17.2 bc
	10	4.3 a–c	14.3 bc	18.6 b
	Fiber	4.5 a–c	14.6 bc	17.3 bc
2 Rubber : 1 vermiculite : 1 peat (by volume)	2.4	3.9 b	13.1 cd	9.7 f
	6	4.5 a–c	13.0 c–e	13.2 e
	10	4.7 a	13.1 cd	14.4 de
	Fiber	4.6 a	13.9 c	16.3 cd
1 Peat : 1 vermiculite (by volume)		4.6 ab	16.0 a	21.3 a
1 Peat : 1 rockwool (by volume)		3.8 cd	15.1 b	16.4 b–d

[z]Mean separation within columns determined by Fisher's protected LSD $P \leq 0.05$.

Table 4. Foliar P, Zn, and Cu concentrations and P : Zn ratio of *Pelargonium ×hortorum* Bailey grown in media containing multiple grind size rubber products from waste tires.

	Particle size	Element			
	or type	P	Zn	Cu	P : Zn
Component	(mm)	($mg\cdot kg^{-1}$ dry mass)			ratio
1 Rubber : 1 peat (by volume)	2.4	3970 cd[z]	247 cd	9.1 bc	17 d
	6	4060 cd	221 c–e	7.5 c–e	19 d
	10	4220 b	174 ef	8.5 b–d	26 d
	Fiber	4570 ab	316 a	13.1 a	15 d
1 Rubber : 1 vermiculite : 2 peat (by volume)	2.4	4140 b–d	261 bc	7.0 c	17 d
	6	4480 a–c	124 f	6.2 d	37 c
	10	4570 ab	96 fg	7.8 cd	49 c
	Fiber	4300 bc	201 de	10.8 ab	22 d
2 Rubber : 1 vermiculite : 1 peat (by volume)	2.4	4000 c	327 a	6.5 de	13 d
	6	3980 c	200 de	6.8 c–e	20 d
	10	3850 d	134 f	5.7 e	29 d
	Fiber	3650 e	296 ab	8.3 bc	13 d
1 Peat : 1 vermiculite (by volume)		4920 a	63 gh	7.1 c–e	146 b
1 Peat : 1 rockwool (by volume)		4890 a	29 h	5.0 e	166 a

[z]Mean separation within columns determined by Fisher's protected LSD $P \leq 0.05$.

Table 5. Mineral analysis of media containing fiber, 2.4-, 6-, and, 10-mm grind products from waste rubber tires compared to the control media.

Component and particle size	Study stage	Element ($mg\cdot kg^{-1}$ dry mass)				
		NO_3-N	P	K	Zn	Cu
Control[z]	Initiation	14	0.2	141	10	2.0
	Middle	34	3.0	904	10	1.6
	Termination	642	64.5	1500	17	2.4
Fiber	Initiation	11	0.2	615	179	22.0
	Middle	16	1.5	527	437	25.4
	Termination	431	60.5	920	611	26.6
Rubber						
2.4 mm	Initiation	11	0.2	15	50	5.7
	Middle	5	1.2	405	357	5.5
	Termination	258	40.3	696	696	4.5
6 mm	Initiation	11	0.2	14	28	3.4
	Middle	6	0.2	445	203	5.2
	Termination	211	31.2	623	623	3.6
10 mm	Initiation	7	1.1	67	26	3.1
	Middle	9	0.8	425	112	2.2
	Termination	177	23.5	521	173	2.8

[z]Two control media: 1 vermiculite : 1 peat, and 1 rockwool : 1 peat, pooled.

study (Table 5). Extractable Zn from the media containing rubber was more than 10 times higher at termination of the study than at initiation. This difference was more pronounced in the media containing the fiber and the 2.4-mm grind, indicating that there was significant release of Zn from the rubber. The largest grind size (10 mm) had lower extractable Zn, most likely due to a smaller surface area for release.

Foliar Cu levels were higher in plants grown in 1 fiber : 1 peat than in plants not grown with fiber in the medium (Table 4), but extractable Cu did not increase over time in the media (Table 5). Foliar P levels were higher in plants grown in the two control media than in those grown in media containing 50% rubber products (Table 4); yet all plants had foliar P levels close to or higher than the critical level of 4,000 $mg\cdot kg^{-1}$ for geraniums (Jones et al., 1991). There was a significant cultivar × grind size interaction influencing P : Zn ratio (Table 2). Excess available Zn tends to disrupt P uptake, as illustrated by the low P : Zn values for media containing 50% rubber products (Boawn and Rasmussen, 1971).

Prior to this study, no use for the fiber from automobile tires had been demonstrated. Waste fiber from rubber grinding is primarily rayon and/or nylon. Fiber has little or no cation exchange capacity (data not shown); however, media with fiber have a water-holding capacity five times that of media with ground rubber (data not shown). Increased water holding capacity increased the nutrients available to the plant (Argo and Biernbaum, 1995) as indicated by higher levels of extractable NO_3-N and K in the media containing fiber compared to ground rubber (Table 5).

A potential deterrent to the use of the fiber is the elevated level of Zn. The fiber used in this study was obtained in an unprocessed form from the waste tire processor and included considerable rubber dust. This dust is assumed to provide the Zn. If the dust could be removed, the fiber would be a viable medium amendment.

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