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Micronutrient Availability in Fresh and Aged Douglas Fir Bark

M. Gabriela Buamscha[1]
Crop and Soil Science Department, Oregon State University, 3017 Ag. Life Sciences Bldg., Corvallis, OR 97331

James E. Altland[2,4]
Department of Horticulture, Oregon State University, North Willamette Research and Extension Center, 15210 NE Miley Road, Aurora, OR 97002

Daniel M. Sullivan[3]
Crop and Soil Science Department, Oregon State University, 3049 Ag. Life Sciences Bldg., Corvallis, OR 97331

Donald A. Horneck[3]
Crop and Soil Science Department, Oregon State University, P.O. Box 105, Hermiston, OR 97838

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Abstract. **Annual vinca [*Catharanthus roseus* (L.) G. Don 'Peppermint Cooler'] plugs were transplanted to containers filled with Douglas fir [*Pseudotsuga menziesii* (Mirbel) Franco] bark (DFB) in May and June 2005 (Expts. 1 and 2, respectively). Treatments were arranged in a 2 × 3 factorial with two DFB ages (fresh and aged) and three micronutrient sources (DFB alone, 10% by volume yard debris compost, or 0.9 kg·m^{-3} Micromax fertilizer). Plants were measured for shoot dry weight and foliar color. Substrate and foliar samples of each plant were analyzed for 13 essential macro- and micronutrients plus substrate pH and EC. Douglas fir bark alone appears to provide sufficient micronutrients for annual vinca grown at pH 4.7 to 5.7 over a 2-month period. In Expt. 1 there were no differences in shoot dry weight or foliar color regardless of DFB age or micronutrient source. At the end of Expt. 2, plants in aged DFB were larger than those in fresh DFB, but differences were primarily the result of nitrogen availability. None of the treatments developed color symptoms that could be associated with micronutrient deficiency. Micronutrient availability in DFB should be considered in container fertilizer management plans.**

Container crops in the Pacific Northwest (PNW) are grown primarily in Douglas fir [*Pseudotsuga menziesii* (Mirbel) Franco] bark (DFB). Similar to pine (*Pinus taeda* L.) bark in the southeast U.S., DFB comprises the highest portion of most nursery substrates (60% to 80% of the substrate mix, personal observation) and is often incorporated to some extent with peatmoss, sand, compost, pumice, and other materials, including fertilizers.

Fresh and aged DFB are used in Oregon (OR) container nurseries. Fresh DFB refers to material sold soon after bark is removed from the tree, ground to smaller particle size, and screened; aged DFB refers to material that goes through the same process but then sits in undisturbed piles (7 to 12 m tall) for an average of 7 months before use. Based on personal conversations with companies that handle DFB, container nurseries are equally divided in their preference for fresh and aged DFB.

Little is known about the chemical and physical properties of DFB with respect to its use as a container substrate, and little is known about the effect of DFB age on its chemical properties. Most information in the literature refers to the chemical properties of soluble components that might be extracted for pulpwood or other industrial chemical purposes (Harkin and Rowe, 1971). Bollen (1969) described the chemical and physical properties of DFB with respect to how surplus bark supplies could be disposed of in an agricultural setting, but provides little information relevant to its use as a container substrate.

Bollen (1969) defined Douglas fir, ponderosa pine (*Pinus ponderosa* P. & C. Lawson), redwood [*Sequoia sempervirens* (Lamb ex D. Don) Endl], and red alder (*Alnus rubra* Bong) bark as materials with low initial fertility. However, research has shown that pine bark media contains sufficient micronutrients to produce woody plants. Niemiera (1992) extracted slightly lower levels of copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn) from pine bark alone compared with pine bark amended with Micromax (The Scotts Co., Marysville, Ohio) or Ironite (Ironite Products Co., Scottsdale, Ariz.); Niemera speculated that such small differences would not be physiologically significant in terms of plant growth. Svenson and Witte (1992) showed that pine bark amended with 25% to 50% composted hardwood bark provided sufficient boron (B), Fe, Mn, and Zn for geranium (*Pelargonium* ×*hortorum* L.) growth.

Research on micronutrient additions to container media and its effect on plant growth have found contrasting results. Rose and Wang (1999) reported no improvement in rhododendron (*Rhododendron* L. × 'Girards Scarlet') growth when adding compost or micronutrient fertilizer to a 3.0 pine bark : 1.0 hardwood bark : 1.0 peat : 0.2 sand (by volume) medium compared with a nonamended control. In contrast, vinca [*Catharanthus roseus* (L.) G. Don] shoot length and dry weight were greatest in a peat-based media with sulfated micronutrients (pH not adjusted) or chelated micronutrients (pH adjusted to 5.5) compared with a nonamended control (Thomas and Latimer, 1995). Wright et al. (1999) analyzed the effect of micronutrient and lime addition on substrate pH and growth of nine container tree species in pine bark; micronutrient additions resulted in the best growth responses for all species, whereas lime depressed growth. Micronutrients increased growth when pH was higher than 5.2 and lime had been applied.

Douglas fir bark in the PNW is used similarly to pine bark in the southeast U.S. Both bark types are irrigated frequently, fertilized with similar products and rates, and mixed with similar components (sand, peatmoss, and so on). Despite similarities in these two resources, several chemical properties of DFB have been found to differ from other conifer barks. For example, bark pH, nitrogen (N), phosphorous (P), potassium (K), calcium (Ca), magnesium (Mg), and C/N ratio differ among Douglas fir, ponderosa pine, and redwood (Bollen, 1969). Research conducted on pine bark with respect to nursery container nutrition cannot be assumed applicable to DFB.

To accurately assess micronutrient status of DFB substrates, a reliable protocol must be used that provides values that are correlated to or predictive of plant micronutrient status. Most laboratories use water extraction for micronutrient analysis, although Warncke (1986) advocates the use of diethylenetriaminepentaacetic acid (DTPA) extraction primarily because it yields larger values.

The objectives of this study were: 1) to evaluate micronutrient availability in fresh and aged DFB; 2) to determine the effect of micronutrient amendments on substrate and

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[1]Graduate research assistant.
[2]Assistant professor.
[3]Associate professor.
[4]To whom reprint requests should be addressed; e-mail James.Altland@oregonstate.edu.

foliar micronutrient levels; and 3) to compare water and DTPA extractions for measuring micronutrient availability in DFB substrates. Our initial hypothesis was that DFB alone provides sufficient micronutrients for annual vinca.

Materials and Methods

Expt. 1. On 5 May 2005, uniform plugs of annual vinca [*Catharanthus roseus* (L.) G. Don 'Peppermint Cooler'] ≈10 cm tall were transplanted to #1 containers (2.8 L) filled with DFB. Treatments were arranged in a 2 × 3 factorial with two DFB ages (fresh and aged) and three micronutrient sources. All bark was ground with a hammer mill and passed through a 0.95-cm screen. Micronutrient sources included incorporating 10% by volume yard debris compost (2.1N–0.2P–0.5K–1.4Ca–0.3Mg–0.001B–0.004Cu–0.9Fe–0.03Mn–0.01Zn) (Rexius Co., Eugene, Ore.), 0.9 kg·m^{-3} Micromax micronutrient fertilizer (6Ca–3Mg–12S–0.10B–1Cu–17Fe–2.5Mn–0.05Mo–1Zn) (The Scotts Co.), or DFB alone (nonamended). Yard debris was composted for 12 weeks and passed through a 1.6-cm screen. All treatments were amended with 1.8 kg·m^{-3} dolomitic limestone (22.7Ca–11.8Mg, 113 calcium carbonate equivalence) (Chemical Lime Lhoist Group, Salinas, Calif.) and 8.9 kg·m^{-3} Osmocote (14N–4.2P–11.6K) (The Scotts Co.). The experiment was conducted in a greenhouse at Oregon State Univ., Corvallis, Ore. Heat and vent greenhouse temperatures were set at 16 and 21 °C, respectively. At 6 weeks after potting (WAP), all plants were measured for foliar color using a SPAD 502 Chlorophyll Meter (Minolta Camera Co., Ramsey, N.J.) and shoot dry weight (SDW) by drying in an oven at 60 °C for 72 h. Recently mature leaves (Mills and Jones, 1996) and the entire growing media were sampled from each plant. Foliar samples were analyzed for N, P, K, Ca, Mg, S, B, Fe, Mn, Cu, and Zn. Foliar N was determined by combustion analysis using a 1500 N analyzer (Carlo Erba, Milan, Italy). The remaining nutrients were determined by inductively coupled plasma-emission spectrometry (ICP) (Thermo Jarrel Ash, Offenbach, Germany). Media samples were analyzed for the same nutrients plus pH and electrical conductivity (EC) using a saturated media extract (SME) method with water and DTPA (Warncke, 1998; Gavlak et al., 2003). Each treatment was replicated seven times in a completely randomized design.

Expt. 2. On 28 July 2005, Expt. 1 was repeated with 16 replications. Eight vinca plants were sampled 5 and 8 WAP each; otherwise, this experiment was conducted similarly to the previous one.

Data from both experiments were subjected to analysis of variance (SAS Institute, 1982) and repeated-measures analysis in Expt. 2 when data were collected twice over time. Measured values for each nutrient parameter are compared with recommended values for substrates (Warncke, 1998) and foliage (Wilkins, 1988).

Results

Expt. 1. At the conclusion of the study, all plants were healthy and vigorous. There were no differences in SDW or foliar color regardless of DFB age and micronutrient source (Table 1).

Bark age and amendments affected substrate pH, although the range of substrate pH was narrow (4.7–5.1, Table 1). Substrate pH was lower in aged DFB compared with fresh DFB. Within each DFB age, containers amended with compost had higher substrate pH than nonamended or Micromax-amended substrates. DTPA-extractable micronutrients in the substrate were not correlated with substrate pH. The highest correlation coefficient was for B (r = –0.380), but even this correlation was weak. Micronutrients in soils and substrates are often correlated to substrate pH (Tisdale et al., 1985). The narrow pH range in this study is most likely responsible for low correlation coefficients.

DTPA B was higher in aged DFB than fresh DFB, but all were below that recommended for potting media. Within each DFB age, Micromax resulted in higher substrate B levels than compost, and compost resulted in higher B levels than DFB alone. Foliar B was correlated to substrate B extracted with DTPA and water (Table 2). Foliar B concentration was below recommended levels in nonamended fresh DFB.

Substrate DTPA Fe was higher in nonamended aged than fresh DFB. All treatments had adequate substrate Fe. However, all foliar Fe remained below the recommended range. Foliar Fe was not correlated to substrate Fe extracted with either DTPA or water (Table 2). Bark age interacted with micronutrient source to affect foliar Fe. Micronutrient source did not influence foliar Fe when added to aged DFB, although compost increased foliar Fe in fresh DFB.

DTPA substrate Mn was higher in fresh than in aged DFB, with the exception of nonamended DFB. Substrate Mn was within the recommended range for all treatments. Foliar Mn was not correlated to DTPA Mn; however, it was highly correlated to water Mn (Table 2). Water substrate Mn was higher in fresh than in aged DFB (data not presented) with the same trend observed in vinca foliage. Within DFB age, Micromax had the highest substrate water Mn (data not presented) and nonamended DFB resulted in the lowest extractable levels. Foliar Mn levels were sufficient in both barks. Micromax increased foliar Mn over nonamended vinca. Micromax in fresh DFB increased foliar Mn to twice the recommended levels.

DTPA substrate Cu was higher in fresh than in aged DFB when amended with Micromax, and all treatments were within or above the recommended range. Foliar Cu was correlated to DTPA Cu but not correlated to water Cu (Table 2). High DTPA Cu in Micromax treatments resulted in adequate foliar Cu, whereas adequate DTPA Cu in the other treatments resulted in less-than-recommended foliar Cu.

Substrate DTPA Zn was higher in fresh than in aged DFB. Substrate Zn was below the recommended range, except for Micromax treatments. Foliar Zn was correlated with DTPA Zn and water Zn (Table 2). Low DTPA Zn in nonamended and compost treatments resulted in sufficient foliar Zn across DFB age. Acceptable DTPA Zn from Micromax caused high foliar Zn in both DFB ages.

Expt. 2. At 5 WAP, micronutrient source did not influence plants size in fresh DFB; however, compost increased plant size in aged DFB (Table 3). At 8 WAP, the aged DFB plants were larger than fresh DFB as a result of differences in N availability (data not shown). Research concurrent with this project has documented greater N immobilization in fresh than aged DFB (Buamscha et al., 2005). In fresh DFB, nonamended vinca were smaller than those amended with compost and Micromax. Aged DFB treatments showed no differences in size between nonamended and amended plants.

Neither DFB age nor micronutrient source affected SPAD levels at 5 and 8 WAP, although visual observations at 8 WAP indicated a darker green color in aged versus fresh DFB (data not shown). Altland et al. (2002) previously reported the inability of SPAD meters to accurately predict N status of annual bedding plants. SPAD meter measurements should be interpreted with caution. No plants developed growth or foliar color symptoms that could be related to micronutrient deficiency or toxicity.

Bark age and micronutrient source interacted to affect substrate pH at 5 and 8 WAP. Similar to Expt. 1, pH differences among treatments were minor and correlations between substrate pH and extractable micronutrients (water or DTPA) were weak (r ≤ 0.377).

Repeated-measures analysis indicates that substrate and foliar B, Fe, Mn, Cu, and Zn decreased between 5 and 8 WAP ($P < 0.0001$). The observed reduction in substrate nutrients may be a consequence of plant uptake and leaching.

At 5 and 8 WAP, compost and Micromax increased substrate B (water and DTPA) in both DFB ages compared with nonamended treatments (Table 3). Similar to Expt. 1, foliar B was correlated with DTPA and water B (Table 2), explaining similarity of treatment effects on substrate and foliar B.

Bark age effect on DTPA-extractable Fe at both sampling dates was similar to Expt. 1. Vinca in aged DFB had higher foliar Fe levels than in fresh DFB, which mimicked the substrate treatment response. Foliar Fe was not correlated to water Fe and weakly correlated to DTPA Fe (Table 2).

Substrate DTPA Mn was similar between fresh and aged DFB at 5 WAP. At 8 WAP, fresh DFB was higher in Mn than aged DFB. Similar to Expt. 1, substrate Mn was the within recommended range across treatments and sampling dates. Foliar Mn was again more correlated to water Mn than to DTPA Mn (Table 2). Only Micromax increased

Table 1. Annual vinca shoot dry weight (SDW), SPAD, and substrate and foliar micronutrients resulting from two bark ages and three micronutrient sources (Expt. 1).

Bark age	Micronutrient source	Plant response		Substrate nutrient availability					
		SDW (g)	SPAD	pH	B (mg·L^{-1})	Fe (mg·L^{-1})	Mn (mg·L^{-1})	Cu (mg·L^{-1})	Zn (mg·L^{-1})
Fresh	None	5.1 a[z]	50.0 a	4.9 b	0.13 e	21.05 c	16.24 ab	0.31 c	2.61 d
Fresh	Compost[y]	4.8 a	53.1 a	5.1 a	0.23 cd	45.85 b	16.46 ab	0.31 c	3.68 c
Fresh	Micromax[x]	5.1 a	50.7 a	4.9 b	0.32 b	56.82 a	19.06 a	5.31 a	8.48 a
Aged	None	4.7 a	50.3 a	4.8 c	0.22 d	44.07 b	15.95 b	0.32 c	3.12 cd
Aged	Compost	4.8 a	51.4 a	4.9 b	0.25 c	46.15 b	7.71 c	0.18 c	2.78 d
Aged	Micromax	4.6 a	50.1 a	4.7 c	0.36 a	46.52 b	6.40 c	2.60 b	5.47 b
Recommended ranges					0.7–2.5[w]	15–40[w]	5–30[w]	0–0.35[v]	5–30[w]
Main effects									
Bark age		NS	NS	***	***	*	***	***	***
Micronutrient		NS	NS	***	***	***	***	***	***
Interaction		NS	NS	NS	**	***	***	***	***

Bark age		Foliar nutrient levels				
		B (mg·kg^{-1})	Fe (mg·kg^{-1})	Mn (mg·kg^{-1})	Cu (mg·kg^{-1})	Zn (mg·kg^{-1})
Fresh	None	22.9 e	78.1 cd	226.3 cd	3.8 b	46.8 c
Fresh	Compost[y]	27.2 d	90.9 a	255.4 c	4.8 b	48.7 c
Fresh	Micromax[x]	39.3 ab	73.8 d	612.2 a	9.6 a	87.9 a
Aged	None	33.1 c	79.1 bcd	188.4 de	2.0 c	44.3 c
Aged	Compost	35.1 bc	83.1 abc	153.0 e	3.6 b	43.8 c
Aged	Micromax	41.4 ab	87.2 ab	314.9 b	8.7 a	77.9 b
Recommended ranges		25–40[u]	95–150[u]	165–300[u]	5–10[u]	40–45[u]
Main effects						
Bark age		***	NS	***	**	*
Micronutrient		***	*	***	***	***
Interaction		*	*	***	NS	NS

[z]Means with different letters within a column and collection date are significantly different separated by least significant difference test ($\alpha \leq 0.05$).
[y]Ten percent by volume yard debris compost.
[x]0.9 kg·m^{-3} Micromax micronutrient fertilizer.
[w]Warncke, D.D. 1998. Recommended test procedure for greenhouse growth media, p. 34–37. In: W.C. Dahnke (ed.), Recommended chemical soil test procedures for the North Central region. North Central Reg. Res. Pub. No. 221. Miss. Agr. Expt. Stat. SB 1001.
[v]Guidelines provided by Brookside Laboratories (New Knoxville, Ohio).
[u]Wilkins, H.F. 1988. University of Minnesota—Tissue analysis standards. Minnesota St. Florist Bulletin. Vol. 37, No. 6.
[NS,*,**,***]Nonsignificant or significant at $P \leq 0.05$, 0.01, and 0.001.
Substrate pH and micronutrients analyzed with a saturated media extract using water and diethylenetriaminepentaacetic acid, respectively.
Foliar nutrients expressed on a dry weight basis.

substrate water Mn and foliar Mn. Foliar Mn levels were within or above the recommended range across all treatments.

Foliar Cu was more correlated to DTPA than water Cu (Table 2). Like in Expt. 1, Micromax resulted in excessive DTPA Cu, but foliar Cu was within the recommended range across DFB ages. Fresh and aged nonamended barks resulted in DTPA Cu levels within or just above recommended ranges but deficient foliar Cu.

Substrate DTPA Zn was higher in aged than in fresh DFB at 5 WAP, whereas no differences existed at 8 WAP. Independent of DFB age and sampling date, DTPA Zn were deficient, near the lower limit, and adequate for the nonamended, compost, and Micromax treatments, respectively. Foliar Zn was correlated to DTPA and water Zn (Table 2). Low DTPA Zn in the nonamended treatments resulted in higher-than-recommended foliar Zn. Micromax increased foliar Zn far higher than recommended, although substrate Zn was within the recommended range.

Table 2. Correlation (r) between each foliar and water or diethylenetriaminepentaacetic acid (DTPA)-extractable substrate micronutrients in annual vinca.

Nutrient	Expt. 1		Expt. 2	
	Water	DTPA	Water	DTPA
B	0.711	0.738	0.674	0.677
Fe	–0.309	–0.097	–0.043	0.602
Mn	0.927	0.297	0.678	0.388
Cu	0.301	0.789	0.276	0.677
Zn	0.923	0.760	0.688	0.793

Discussion

Douglas fir bark without amendment provides sufficient micronutrients for annual vinca over a 2-month period. The findings are similar to research of Niemiera (1992), Svenson and Witte (1992), and Rose and Wang (1999) in pine bark substrates. Substrate and foliage micronutrients declined from 5 to 8 WAP and might decline even more over the course of a long production period (several months) for woody crops. Others have found that substrate micronutrient supply over the course of a growing season is relatively constant and unaffected by irrigation (Broschat and Donselman, 1985; Niemiera, 1992). Substrate pH was low in this experiment. Because micronutrients are responsive to substrate pH, elevated pH might reduce micronutrient levels and impact plant growth more than what occurred in this study. Increase in substrate pH resulting from water alkalinity might gradually reduce micronutrient availability in woody crops with longer production cycles. Until more research addresses longevity of micronutrient availability in DFB and responsiveness to substrate pH, it can only be concluded that DFB is a reliable micronutrient source for crops with short production cycles being grown at pH 4.7 to 5.7.

Nonamended plants in fresh bark were smaller than amended ones at the end of Expt. 2. Micronutrient nutrition cannot explain these growth differences for two reasons: 1) compost and nonamended plants had similar foliar nutrients levels except for B, and 2) Micromax-amended plants had higher foliar Ca, Mg, S (data not presented), Mn, Cu, and Zn than nonamended; however, the same trend occurred in aged DFB and did not affect plant growth. Foliar N was reduced in plants growing in fresh compared with aged DFB (3.2 versus 4.7%, respectively, data not presented). Micronutrient source did not affect N and thus does not explain differences observed between the two DFB ages.

No broad generalization can be made as to which DFB age (fresh or aged) provides greater micronutrient nutrition. After 8 weeks, plants in both barks had the highest foliar levels of Mn, Cu, and Zn when amended with Micromax. Higher foliar micronutrient concentrations did not improve crop dry weight or color. Within both DFB ages, plants amended with compost and Micromax were similar in size and color. Similarly, Rose and Wang (1999) found no growth differences between treatments amended with compost and micronutrient fertilizers.

Table 3. Annual vinca shoot dry weight (SDW), SPAD, and substrate and foliar micronutrients resulting from two bark ages and three micronutrient sources (Expt. 2).

Bark age	Micronutrient source	Plant response		Substrate nutrient availability					
		SDW (g)	SPAD	pH	B (mg·L^{-1})	Fe (mg·L^{-1})	Mn (mg·L^{-1})	Cu (mg·L^{-1})	Zn (mg·L^{-1})
				Data collected 5 WAP[t]					
Fresh	None	4.6 bc[z]	59.4 a	5.6 a	0.14 d	29.78 d	18.88 c	0.48 cd	3.51 d
Fresh	Compost[y]	4.7 bc	57.8 a	5.7 a	0.21 c	57.02 c	27.23 ab	0.74 c	5.42 c
Fresh	Micromax[x]	4.9 ab	59.4 a	5.3 b	0.26 b	86.60 b	28.05 ab	4.90 a	13.39 b
Aged	None	4.2 c	58.9 a	5.2 c	0.21 c	×62.26 c	18.31 c	0.37 d	3.95 d
Aged	Compost	5.5 a	59.4 a	5.3 bc	0.31 a	91.06 b	25.30 b	0.71 c	5.95 c
Aged	Micromax	4.4 bc	61.4 a	5.3 bc	0.33 a	113.48 a	28.50 a	4.20 b	14.37 a
				Data collected 8 WAP					
Fresh	None	7.9 c	53.3 a	5.3 ab	0.13 d	27.07 d	16.15 c	0.37 d	2.79 c
Fresh	Compost	11.1 b	52.1 a	5.4 a	0.18 c	43.84 c	22.47 a	0.61 c	4.46 b
Fresh	Micromax	11.1 b	51.2 a	5.2 bc	0.19 bc	54.92 b	18.96 b	3.44 a	9.68 a
Aged	None	12.7 a	50.0 a	5.1 d	0.20 b	56.23 b	12.25 d	0.33 d	3.27 c
Aged	Compost	13.5 a	55.8 a	5.2 bc	0.27 a	70.24 a	16.74 bc	0.49 cd	4.86 b
Aged	Micromax	12.0 ab	51.0 a	5.2 c	0.25 a	69.81 a	13.45 d	2.97 b	9.63 a
Recommended ranges					0.7–2.5[w]	15–40[w]	5–30[w]	0–0.35[v]	5–30[w]
Main effects									
Bark age (B)		***	NS	***	***	***	***	***	**
Micronutrient source (M)		***	NS	***	***	***	***	***	***
B*M		**	NS	***	NS	**	NS	***	NS
Date (D)		***	***	***	***	***	***	***	***
B*D		***	NS	**	NS	*	***	NS	NS
M*D		NS	NS	NS	***	***	***	***	***
B*M*D		***	NS	NS	NS	NS	NS	NS	NS

Bark age		Foliar nutrient levels				
		B (mg·kg^{-1})	Fe (mg·kg^{-1})	Mn (mg·kg^{-1})	Cu (mg·kg^{-1})	Zn (mg·kg^{-1})
		Data collected 5 WAP[t]				
Fresh	None	20.7 c	85.4 d	357.3 bc	4.7 c	58.5 c
Fresh	Compost[y]	26.7 b	90.3 cd	306.3 c	5.9 b	57.4 c
Fresh	Micromax[x]	21.6 c	94.3 c	561.7 a	8.7 a	102.6 a
Aged	None	33.9 a	115.1 a	397.8 b	3.4 d	70.9 b
Aged	Compost	34.0 a	104.2 b	380.0 b	5.1 bc	63.5 bc
Aged	Micromax	36.1 a	109.2 ab	585.3 a	8.7 a	105.6 a
		Data collected 8 WAP				
Fresh	None	15.5 d	62.2 b	228.8 c	2.5 d	47.6 c
Fresh	Compost	19.8 bc	68.8 b	202.3 c	3.1 cd	44.8 c
Fresh	Micromax	17.8 cd	65.2 b	299.7 b	4.0 bc	70.3 b
Aged	None	22.1 b	93.7 a	252.7 bc	3.5 cd	60.3 b
Aged	Compost	34.2 a	91.1 a	304.3 b	5.3 b	65.0 b
Aged	Micromax	32.7 a	94.1 a	496.1 a	8.5 a	105.5 a
Recommended ranges		25–40[u]	95–150[u]	165–300[u]	5–10[u]	40–45[u]
Main effects						
Bark age (B)		***	***	***	***	***
Micronutrient source (M)		***	NS	***	***	***
B*M		*	*	NS	***	NS
Date (D)		***	***	***	***	***
B*D		NS	*	**	***	***
M*D		*	NS	**	*	NS
B*M*D		**	NS	**	NS	*

[z]Means with different letters within a column and collection date are significantly different separated by least significant difference test ($\alpha \leq 0.05$).
[y]Ten percent by volume yard debris compost.
[x]0.9 kg·m^{-3} Micromax micronutrient fertilizer.
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[v]Guidelines provided by Brookside Laboratories (New Knoxville, Ohio).
[u]Wilkins, H.F. 1988. University of Minnesota—Tissue analysis standards. Minnesota St. Florist Bulletin. Vol. 37, No. 6.
[t]Weeks after planting.
[NS,*, **, ***]Nonsignificant or significant at $P \leq 0.05$, 0.01, and 0.001.
Substrate pH and micronutrients analyzed with a saturated media extract using water and diethylenetriaminepentaacetic acid, respectively.
Foliar nutrients expressed on a dry weight basis.

Guidelines for soilless substrates developed by Warncke (1998) do not always match foliar guidelines developed for individual crops. Warncke's guidelines indicate that nonamended fresh and aged DFB do not have adequate B and Zn by 8 WAP. However, foliar guidelines for annual vinca by Wilkins (1988) indicate that fresh and aged DFB supplies sufficient foliar Zn. Specific foliar guidelines for annual vinca are probably more reliable than general substrate guidelines; however, Wilkins' foliar micronutrient guidelines for annual vinca are not always supported by our observations. For example, in Expt.1, Micromax increased foliar Mn in fresh DFB and foliar Zn in both barks to levels considerably higher than recommended, although plants did not show symptoms of Mn or Zn toxicity. A possible explanation for this discrepancy is that Wilkins' foliar guidelines were not defined by vinca growth stage.

Warncke (1998) recommends DTPA to enhance the extraction of Zn, Mn, and Fe. In this study, we saw increased extraction of the mentioned micronutrients plus Cu when using DTPA compared with water. Increased

extraction of a particular micronutrient does not necessarily correlate with solution concentration available for plant absorption. Handreck and Black (2002) also recommend DTPA because of increased Fe in substrates with increasing Fe amendment rates. However, increased Fe would be expected in substrates with increased amendment rates, and again this does not imply increased nutrient availability for plants. In agronomic crops, nutrient availability is measured with a variety of extractants with the most useful being that which correlates most closely to yield. Ornamental crops, and annual vinca in particular, do not produce a harvestable yield in terms of fruit or fiber. The best gauge of how well an extractant works (water or DTPA) with ornamental crops is how well it correlates to foliar nutrient levels. In this study, foliar Mn was more highly correlated with water Mn and foliar Cu with DTPA Cu, whereas foliar B and Zn were correlated to both extractants. Rose and Wang (1999) reported a lack of correlation between foliar and substrate DTPA Fe, Cu, Zn, and B. More research is required to closely compare extractants for nutrient availability in DFB and other substrates.

In summary, these data demonstrate that DFB is an important source of micronutrients for container-grown crops. Boron and Cu may appear to be deficient depending on which set of guidelines or experimental results are considered. Longevity and pH responsiveness of micronutrient availability is still not known. These results cannot rule out recommendations for use of micronutrient amendments; however, they do suggest micronutrient availability in DFB be considered in container fertilizer management plans.

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