Research Reports

WholeTree Substrates Derived from Three Species of Pine in Production of Annual Vinca

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**Summary. The objective of this study was to evaluate the potential for use of container substrates composed of processed whole pine trees (*WholeTree*). Three species [loblolly pine (*Pinus taeda*), slash pine (*Pinus elliottii*), and longleaf pine (*Pinus palustris*)] of 8- to 10-year-old pine trees were harvested at ground level and the entire tree was chipped with a tree chipper. Chips from each tree species were processed with a hammer mill to pass through a 0.374-inch screen. On 29 June 2005 1-gal containers were filled with substrates, placed into full sun under overhead irrigation, and planted with a single liner (63.4 cm³) of 'Little Blanche' annual vinca (*Catharanthus roseus*). The test was repeated on 27 Aug. 2005 with 'Raspberry Red Cooler' annual vinca. Pine bark substrate had about 50% less air space and 32% greater water holding capacity than the other substrates.
At 54 days after potting (DAP), shoot dry weights were 15% greater for plants grown in 100% pine bark substrate compared with plants grown in the three *WholeTree* substrates. However, there were no differences in plant growth indices for any substrate at 54 DAP. Plant tissue macronutrient content was similar among all substrates. Tissue micronutrient content was similar and within sufficiency ranges with the exception of manganese. Manganese was highest for substrates made from slash pine and loblolly pine. Root growth was similar among all treatments. Results from the second study were similar. Based on these results, *WholeTree* substrates derived from loblolly pine, slash pine, or longleaf pine have potential as an alternative, sustainable source for producing short-term horticultural crops.**

Peat moss and pine bark are the primary components of growth substrates in the production of container-grown herbaceous crops. However, there is concern that the availability of pine bark for horticultural usage might be limited as a result of alternative demands such as industrial fuel (Cole et al., 2002; Haynes, 2003). Other factors affecting the future availability of pine bark are reduced forestry production and increased importation of logs already debarked (Lu et al., 2006). Environmental impacts of peat harvesting have been debated for years in Europe. Barkham (1993) stated that there is no longer a need to use peat for the wide variety of garden, commercial, horticultural, and landscape uses for which it has been promoted over the last 30 years. Robertson (1993) states that the Peat Producers Association in Europe produce and market more than 100 low-peat or nonpeat products.

Many alternative substrate components have been evaluated. Some substrates have been evaluated as additions to reduce the quantities of pine bark and peatmoss in a given substrate and others as replacements for pine bark and peatmoss. Components that have been evaluated include but are not limited to hardwood bark (Bilderback, 1981; Gartner et al., 1972; Morris and Milbocker, 1972), poultry litter (Bilderback and Fonteno, 1991; Tyler et al., 1993), municipal wastes (Bugbee, 1994; Rosen et al., 1993), rice hulls (Papafotiou et al., 2001), and cotton gin trash (Cole et al., 2002; Owings, 1993). Coconut coir has shown promise as a peat substitute (Evans and Stamps, 1996; Fain et al., 1998). However, the high transportation costs from Sri Lanka

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.0283	ft³	m³	35.3147
3.7854	gal	L	0.2642
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
16.3871	inch³	cm³	0.0610
0.5933	lb/yard³	kg·m⁻³	1.6856
1	mmho/cm	dS·m⁻¹	1
28.3495	oz	g	0.0353
1.7300	oz/inch³	g·cm⁻³	0.5780
1	ppm	mg·kg⁻¹	1
(°F – 32) ÷ 1.8	°F	°C	(1.8 × °C) + 32

and Malaysia and a certain degree of inconsistency in quality (Bragg, 1991) are among the factors that have limited its widespread acceptance. With many, if not all, of the alternative substrates that have been evaluated, the biggest obstacle is perhaps the availability of a consistent quality product in quantities to sustain the industry into the future.

Some of the more promising alternatives currently used in Europe are those made of wood fiber. Studies by Gruda et al. (2000) and Gruda and Schnitzler (2001) demonstrated the suitability of wood fiber substrates as an alternative for peat-based substrates in cultivation of lettuce seedlings (*Lactuca sativa*) and tomato transplants (*Solanum lycopersicum*). Although not on the market in the United States, there are at least seven well-known wood fiber products marketed in Europe (Gumy, 2001). Estimates from Germany in 1999 revealed that more than 180,000 m^3 of wood fiber is marketed annually (Gumy, 2001). Boyer et al. (2006) reported container-grown lantana (*Lantana camara*) could be produced in substrates containing from 50% to 100% processed whole loblolly pine shoots. Wright and Browder (2005) demonstrated that 'Chesapeak' japanese holly (*Ilex crenata*) grown in a wood fiber substrate made from loblolly pine chips performed as well as those grown in a standard pine bark substrate.

WholeTree is a substrate made from whole pine trees (aboveground portions: wood, bark, needles, cones, etc.) and thus consists of ≈80% wood fiber. What is most promising about *WholeTree* is its sustainability and availability in close proximity to major horticultural production areas and, unlike previously studied wood fiber substrates, the entire shoot portions of the tree are used. Utilization of all shoot portions of the tree will maximize the biomass yield and reduce the production costs associated with manufacturing the substrates. Another advantage of *WholeTree* substrates is that during the manufacturing process the finished product can be altered and tailored to the required application purposes with respect to physical properties such as particle size and porosity. Because *WholeTree* is manufactured it can also be produced with a consistent quality over time. The objective of the research presented here was to evaluate three *WholeTree* substrates made form three species of processed whole pine trees as alternative growth substrates for container-grown annual vinca.

Materials and methods

Eight- to 10-year-old loblolly pine, longleaf pine, and slash pine were harvested at ground level and the entire shoot portion of the trees was chipped with a tree chipper (model 725H; PowerTek, Lebanon, IN). This resulting material, containing all shoot portions of the tree (wood, cambium, bark, needles, and cones) was then further processed with a hammer mill (model 30; C.S. Bell Co., Tiffin, OH) to pass through a 0.374-inch screen.

On 29 June 2005, 4 d after harvesting trees from the forest, the three *WholeTree* substrates along with 100% pine bark were amended with 16 lb/yard^3 18N–2.6P–10K (7 to 8-month release at 32 °C; Pursell Technologies, Sylacauga, AL), 3 lb/yard^3 dolomitic lime, and 1.5 lb/yard^3 Micromax (Scotts Co., Marysville, OH). Containers (1 gal) were filled and placed on a crushed limestone surface in full sun at the Southern Horticultural Laboratory in Poplarville, MS (lat. 30°50′N, long. 89°32′W). Each container received one uniform annual vinca liner (63.4 cm^3). Plants were watered with overhead irrigation (MP3000; Walla Walla Sprinkler Co., Walla Walla, WA) at a rate of 1 inch/h. Plants received ≈0.34 inch once daily until 30 d after planting (DAP), at which time they received 0.34 inch twice daily until study completion. Average daily temperature for the duration of the study was 27.2 °C whereas average daily minimum and maximums were 23.0 °C and 34.9 °C respectively.

Substrates were analyzed for particle size distribution (PSD) by passing a 100-g air-dried sample through 12.5, 9.5, 6.35, 3.35, 2.36, 2.0, 1.4, 1.0, 0.5, 0.25, and 0.11-mm sieves with particles passing the 0.11-mm sieve collected in a pan. Sieves were shaken for 3 min with a Ro-Tap sieve shaker [278 oscillations/min, 159 taps/min (Ro-Tap RX-29; W.S. Tyler, Mentor, OH)]. Substrate air space (AS), container capacity (CC), and total porosity were determined following the procedures described by Bilderback et al. (1982). Substrate bulk density (measured in grams per cubic centimeters) was determined from 347.5-cm^3 samples dried in a 105 °C forced-air oven for 48 h. Substrate pH and electrical conductivity (EC) were determined for Expt. 1 before incorporation of substrate amendments as well as 7 and 30 DAP using the pour-through method. At 54 DAP, all plants were measured for growth index [(height + width + perpendicular width)/3], leaf greenness (SPAD 502 chlorophyll meter; Minolta Camera Co., Ramsey, NJ), and shoot dry weight by drying in a forced-air oven at 70 °C for 48 h. Roots were visually inspected and rated on a scale of 0 to 5 points, with 0 point indicating no roots present at the container substrate interface and 5 points indicating roots visible at all portions of the container substrate interface. Recently matured leaves (Mills and Jones, 1996) were sampled from seven and four replications from Expts. 1 and 2 respectively. Foliar samples were analyzed for nitrogen (N), phosphorus, potassium (K), calcium (Ca), magnesium, sulfur, boron, iron, manganese (Mn), copper, and zinc. Foliar N was determined by combustion analysis using a 1500 N analyzer (Carlo Erba, Milan, Italy). Remaining nutrients were determined by microwave digestion with inductively coupled plasma-emission spectrometry (Thermo Jarrel Ash, Offenbach, Germany). Eight single-plant replicates per treatment were arranged in a randomized complete block. Multiple comparison of means were conducted using a Bonferroni *t* test at $\alpha = 0.05$. The test was repeated on 27 Aug. 2005 and ended at 40 DAP. Plants were watered as in Expt. 1 with the exception of from 30 Aug. until 11 Sept. plants were hand watered as needed as a result of failure of the irrigation system resulting from hurricane Katrina. *WholeTree* substrates used in Expt. 2 were made from the same batch of chips as the first study. Average daily temperature for the duration of the second study was 26.3 °C whereas average daily minimum and maximums were 22.3 °C and 32.9 °C respectively.

Results and discussion

WholeTree substrates had, on average, twice the AS and 14% less CC than the pine bark substrate

(Table 1). Particle size distribution provides some explanation for the differences in air space and water holding capacity. Substrate PSD indicates that the pine bark substrate used in this study had 7% more small (<1.0 mm) particles, 24% less medium (<6.35–1.0 mm) particles, and 15% more large (>6.35 mm) particles than the average of the three *WholeTree* substrates (Table 2). According to Bohne and Günther (1997) a reduction in particle size leads to a decrease in AS. Total porosity and bulk density were within the recommended ranges for all substrates (Yeager et al., 1997). However, total AS was higher and CC was lower for *WholeTree* substrates made from either slash or longleaf pine. With the *WholeTree* substrate made from loblolly pine, CC was within recommended ranges but AS, although lower than the other *WholeTree* substrates, was still higher than the recommended range of 10% to 30%. High AS and low CC in *WholeTree* substrates did not appear to have a negative effect on the plants in this study.

Initial (before addition of amendments) substrate pH indicated that *WholeTree* made from either slash or longleaf pine had an average pH of 4.5 and was lower than that of pine bark or *WholeTree* made from loblolly pine, both of which had a pH of 5.3 (Table 3). Initial substrate EC revealed that *WholeTree* substrates had two to three times the EC of pine bark. The EC of fresh *WholeTree* substrate is most likely being contributed by soluble salts in the tree released at grinding, especially from the foliage. Substrate analysis at 7 and 30 DAP indicated that the pH was higher than the recommended range of 5.4 to 6.2 for annual vinca (Argo and Fisher, 2002) for all substrates (Table 3). There were no visual symptoms, nor tissue nutrient deficiencies that would indicate that the high pH adversely affected the plants. At 7 and 30 DAP, all substrates had similar EC and were at the suggested levels for container-grown plants fertilized with controlled-release fertilizer only (Yeager et al., 1997), and similar to previous studies using controlled-release fertilizer and pine bark substrates (Bilderback et al., 1999; Fain et al., 1998; Ivy et al., 2002).

There were no differences in leaf greenness for any substrate for either

Table 1. Physical properties of pine bark and container substrates composed of processed whole pine trees (*WholeTree*) used in the production of annual vinca at Poplarville, MS, from June 2007 to Oct. 2007.[z]

Substrates	Air space (%)[y]	Container capacity (%)[x]	Total porosity (%)[w]	Bulk density ($g\cdot cm^{-3}$)[v]
Pine bark	20 c[u]	56 a	76 b	0.23 a
WholeTree (loblolly pine)[t]	38 b	47 b	84 a	0.16 b
WholeTree (slash pine)	44 a	40 c	84 a	0.16 b
WholeTree (longleaf pine)	43 a	41 c	84 a	0.17 b
Sufficiency range[s]	10–30	45–65	50–85	0.19–0.70

[z]Analysis performed using the North Carolina State University porometer.
[y]Air space is volume of water drained from the sample ÷ volume of the sample.
[x]Container capacity is (wet weight – oven dry weight) ÷ volume of the sample.
[w]Total porosity is container capacity + air space.
[v]Bulk density after forced-air drying at 105 °C (221.0 °F) for 48 h; 1 $g\cdot cm^{-3}$ = 0.5780 $oz/inch^3$.
[u]Mean separation within column by Bonferroni *t* test (α = 0.05, n = 4).
[t]Eight- to 10-year-old loblolly pine, slash pine, or longleaf pine harvested at ground level, chipped, and hammer milled to pass through a 0.374-inch (0.95-cm) screen.
[s]Sufficiency ranges as reported by Yeager et al. (1997).

Table 2. Particle size distribution of pine bark and container substrates composed of processed whole pine trees (*WholeTree*) used in the production of annual vinca at Poplarville, MS, from June 2007 to Oct. 2007.

			WholeTree (%)[y]		
U.S. standard sieve no.	Sieve opening (mm)[z]	Pine bark (%)	Loblolly pine	Slash pine	Longleaf pine
1/2	12.50	3.8 a[x]	0.0 b	0.0 b	0.0 b
3/8	9.50	5.5 a	0.0 b	0.0 b	0.0 b
1/4	6.35	12.9 a	9.4 ab	6.5 bc	4.5 c
6	3.35	28.9 c	38.2 b	43.1 a	42.1 a
8	2.36	14.5 c	18.1 b	20.5 a	18.6 ab
10	2.00	3.6 c	5.8 b	6.6 a	6.8 a
14	1.40	8.2 c	12.6 a	10.4 b	12.2 a
18	1.00	5.0 b	7.9 a	5.1 b	5.2 b
35	0.50	7.5 a	5.5 b	6.1 b	5.4 b
60	0.25	4.8 a	1.8 c	2.4 b	2.1 bc
140	0.11	3.3 a	0.6 c	0.9 b	0.8 bc
pan	0.00	0.2 a	0.1 c	0.4 b	0.3 bc

[z]1 mm = 0.0394 inch.
[y]Eight- to 10-year-old loblolly pine, slash pine, and longleaf pine harvested at ground level, chipped, and hammer milled to pass through a 0.374-inch (0.95-cm) screen.
[x]Percent weight of sample collected on each screen. Mean separation within row by Bonferroni *t* test (α = 0.05, n = 3).

Table 3. Solution pH and electrical conductivity (EC) of pine bark and container substrates composed of processed whole pine trees (*WholeTree*) in production of annual vinca at Poplarville, MS, from June 2007 to Aug. 2007.[z]

	Initial[y]		7 DAP[x]		30 DAP	
Substrates	pH	EC ($dS\cdot m^{-1}$)	pH	EC ($dS\cdot m^{-1}$)	pH	EC ($dS\cdot m^{-1}$)
Pine bark	5.3 a[w]	0.21 c	6.8 a	0.24 a	6.8 b	0.28 a
WholeTree (loblolly pine)[v]	5.3 a	0.52 b	6.8 a	0.55 a	7.1 a	0.26 a
WholeTree (slash pine)	4.5 b	0.52 b	6.6 a	0.41 a	6.9 ab	0.26 a
WholeTree (longleaf pine)	4.6 b	0.78 a	6.8 a	0.53 a	7.2 a	0.20 a

[z]pH and electrical conductivity (EC) of solution obtained by the pour-through method.
[y]pH and EC of substrate before pH adjustment and incorporating of nutrients (1 $dS\cdot m^{-1}$ = 1 mmho/cm).
[x]DAP, days after potting for first experiment with 'Little Blanche'.
[w]Mean separation within column by Bonferroni *t* test (α = 0.05, n = 4).
[v]Eight- to 10-year-old loblolly pine, slash pine, or longleaf pine harvested at ground level, chipped, and hammer milled to pass through a 0.374-inch (0.95-cm) screen.

test (Table 4). All plants in both tests had similar growth indices with the exception of those grown in the processed loblolly pine substrate in Expt. 1, which were 20% smaller than those grown in pine bark substrate. During Expt. 1, shoot dry weights were greatest for plants grown in the pine bark substrate followed by plants grown in the longleaf and slash substrates. The smallest plants were those grown in the loblolly substrate.

There were no differences in plant tissue macronutrient content for any substrate. Macronutrients were within sufficiency ranges reported by Mills and Jones (1996) with the exception of Ca, which was below the reported sufficiency range for both tests; and K, which was below the reported sufficiency range in Expt. 1 (Table 5). Tissue micronutrient content was similar and also within sufficiency ranges with the exception of Mn. Manganese was highest for slash and loblolly pine substrates and well over the reported sufficiency range. However, there were no visual signs of Mn toxicity. There were no differences in root ratings between any substrate tested (data not shown).

Although the issue of N immobilization was not addressed in this study, Gruda et al. (2000) reported that N immobilization occurring in wood fiber resulted in needed N not being available for plants. Although some N immobilization undoubtedly occurred in all substrates, we believe there was sufficient N available to the plants. Similar EC, tissue analysis, and leaf greenness between substrates indicate that under these production criteria N immobilization was not a limiting factor. The differences in annual vinca growth between *WholeTree* and pine bark is more likely the result of the physical properties of substrates in which higher AS and lower CC resulted in less available water to plants grown in the *WholeTree* substrates. This could be overcome by an adjustment in irrigation practices, such as using cyclic irrigation to apply smaller water amounts more frequently. However, physical properties of *WholeTree* substrates can also be addressed during the manufacturing process. It is possible that initial physical properties can be

Table 4. Growth of annual vinca grown in pine bark and container substrates composed of processed whole pine trees (*WholeTree*) in studies conducted at Poplarville, MS, from June 2007 to Oct. 2007.

Substrates	SPAD[z]	GI (cm)[y]	Dry wt (g)[x]
Expt. 1: 'Little Blanche'[w]			
Pine bark	50.2 a[v]	32.0 a	30.1 a
WholeTree (loblolly pine)[u]	54.0 a	26.6 b	20.1 c
WholeTree (slash pine)	52.2 a	30.1 ab	23.3 b
WholeTree (longleaf pine)	51.7 a	29.8 ab	24.1 b
Expt. 2: 'Raspberry Red Cooler'[t]			
Pine bark	56.4 a	21.5 a	14.6 a
WholeTree (loblolly pine)	57.1 a	20.7 a	11.0 b
WholeTree (slash pine)	56.1 a	22.2 a	12.9 ab
WholeTree (longleaf pine)	54.2 a	19.8 a	12.1 ab

[z]Leaf greenness of four recently matured leaves per plant using an SPAD 502 chlorophyll meter (Minolta Camera Co., Ramsey, NJ).
[y]Growth index (GI) = (height + width + perpendicular width)/3; 1 cm = 0.3937 inch.
[x]Shoots harvested at container surface and oven dried at 70 °C (158.0 °F) for 48 h; 1 g = 0.0353 oz.
[w]Data collected 54 d after potting.
[v]Mean separation within column by Bonferroni *t* test (α = 0.05; Expt. 1, n = 8; Expt. 2, n = 7).
[u]Eight- to 10-year-old loblolly pine, slash pine, or longleaf pine harvested at ground level, chipped, and hammer milled to pass through a 0.374-inch (0.95-cm) screen.
[t]Data collected 40 d after potting.

Table 5. Tissue nutrient content of annual vinca grown in pine bark and container substrates composed of processed whole pine trees (*WholeTree*) in studies conducted at Poplarville, MS, from June 2007 to Oct. 2007.

	Tissue macronutrient content (%)[z]						Tissue micronutrient content (ppm)				
Substrates	N	P	K	Ca	Mg	S	B	Fe	Mn	Cu	Zn
Expt. 1: 'Little Blanche'											
Pine bark	5.0 a[y]	0.35 a	1.6 a	0.90 a	0.41 a	0.33 a	30 b	97 ab	302 b	6.7 a	64 a
WholeTree (loblolly pine)[x]	4.6 a	0.34 a	1.7 a	0.92 a	0.38 a	0.32 a	37 a	103 a	180 c	5.2 b	56 b
WholeTree (slash pine)	5.0 a	0.35 a	1.8 a	0.89 a	0.38 a	0.31 a	33 ab	95 ab	397 ab	6.5 ab	63 a
WholeTree (longleaf pine)	5.2 a	0.37 a	1.7 a	0.82 a	0.41 a	0.35 a	32 b	89 b	472 a	7.4 a	70 a
Expt. 2: 'Raspberry Red Cooler'											
Pine bark	5.8 a	0.47 a	2.3 a	0.70 a	0.40 a	0.43 a	57 a	153 a	237 b	8.2 a	47 a
WholeTree (loblolly)	5.5 ab	0.41 a	2.0 a	0.68 a	0.40 a	0.41 a	51 a	136 a	172 b	7.1 a	48 a
WholeTree (slash)	5.2 b	0.42 a	2.3 a	0.61 a	0.38 a	0.43 a	50 a	121 a	442 a	8.1 a	48 a
WholeTree (longleaf)	5.7 ab	0.45 a	2.2 a	0.69 a	0.40 a	0.46 a	52 a	139 a	124 b	7.1 a	38 b
Sufficiency range[w]	2.72–6.28	0.28–0.64	1.88–3.48	0.93–1.13	0.32–0.78	0.22–0.50	21–49	72–277	135–302	6–16	30–51

[z]Tissue analysis performed on 30 recently mature leaves per plant. N, nitrogen; P, phosphorus; K, potassium; Ca, calcium; Mg, magnesium; S, sulfur; B, boron; Fe, iron; Mn, manganese; Cu, copper; Zn, zinc; 1 ppm = 1 $mg \cdot kg^{-1}$.
[y]Mean separation within column by Bonferroni *t* test (α = 0.05; Expt. 1., n = 7; Expt. 2, n = 4).
[x]Eight- to 10-year-old loblolly pine, slash pine, or longleaf pine harvested at ground level, chipped, and hammer milled to pass through a 0.374-inch (0.95-cm) screen.
[w]Sufficiency ranges as published by Mills and Jones (1996).

brought within recommended ranges by adjusting the milling process to achieve the desired properties. Based on these results, *WholeTree* substrates derived from loblolly pine, slash pine, or longleaf pine have potential as an alternative, sustainable source for producing short-term horticultural crops. Postharvest issues such as plant performance in the garden center and landscape environments should be addressed.

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